中央研究院
天文及天文物理研究所

Academia Sinica Institute of Astronomy and Astrophysics

Research Highlights
研究成果專刊

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Letter from the Director

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Dear Colleagues and Friends:

As proposed by Academician Chia-Chiao Lin and approved by the Academia Sinica with the support of Academy President Ta-You Wu, the Preparatory Office of the Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) was established in 1993. During these intervening years, our researches have become competitive at the frontier, and our staffs of young scientists have achieved international recognition for their accomplishments. On June 1, 2010, the ASIAA became a full-fledged institute.

The mission of our Institute has been to construct forefront facilities, to gain access to advanced instruments, and to engage in research on fundamental astrophysical problems. Our emphasis has been on developing innovative technology that will substantially increase the sensitivity in order to drive the progress in our discipline. We focus our research initiatives and we concentrate our resources in order to work on the most important topics. In this brochure, we report on the current progress and the scientific achievements from the large projects at our Institute. We also present scientific highlights from our research staff members, who are pursuing studies ranging from planet formation to cosmology. Our observational investigations cover all wavelength bands. Our theoretical studies utilize both analytical and numerical methods. Our instrumentation projects are in the radio, optical, and infrared windows. In these past few years, we are also increasing our efforts in education and public outreach. These are also described.

The success of our Institute has been guided by a succession of Directors, starting with Typhoon Lee, Chi Yuan, Kwok-Yung Lo, and Sun Kwok. We are grateful for the support of past Academy President Yuan-Tseh Lee, and our current Academy President Chi-Huey Wong. The hard work of our scientists, engineers, students, and administrative staffs, have earned the achievements of our Institute. As scientists, we are fortunate to be able to study such fundamental problems as the origin of life, the formation of planets and stars, the mystery of black holes, the evolution and fate of galaxies and the universe itself, and the existence of dark matter and dark energy. We are mindful that our work have been supported by public funds from the people of Taiwan. We also thank our friends and collaborators who work with us all around the world. With this brochure, we look forward to continue to engage the interest of young people and the general public by sharing our excitement in working on the forefront problems in modern astronomy.

Paul T.P. Ho 5.03.2012

Introduction

Introduction

The Academia Sinica Institute of Astronomy and Astrophysics (ASIAA) is one of the 31 institutes and centers of the Academia Sinica. Our Preparatory Office was established in 1993, and we became a full-fledged institute in 2010. The ASIAA is located in the Astronomy-Mathematics Building (ASMAB) on the campus of the National Taiwan University (NTU). We now have a staff of around 180, including research fellows, research engineers and scientists, postdoctoral fellows, visiting scholars, assistants and supporting personnel.

ASIAA works at the forefronts of astronomical research. We concentrate our efforts in specific directions, building up core groups in instrumentation, experimental astrophysics, and theory.

During the first decade of ASIAA, the focus of our development has been on radio astronomy. Starting with a training effort on millimeter wavelength interferometry with the Berkeley-Illinois-Maryland Association (BIMA), ASIAA soon became a partner of the Submillimeter Array (SMA) in 1996. In 2000, ASIAA led the design and construction of the Array for Microwave Background Anisotropy (AMiBA) together with NTU. In 2005, Taiwan joined the international Atacama Large Millimeter/submillimeter Array (ALMA) project. In 2009, ASIAA began a program in submillimeter wavelength Very Long Baseline Interferometry, to deploy the Greenland Telescope (GLT). These efforts have led to the establishment of the Receiver Laboratory, the Microwave Device Laboratory, and the Superconducting Device Laboratory, at ASIAA.

During the second decade of ASIAA, we also began our development in optical and infrared astronomy. ASIAA collaborated with National Central University (NCU) and Lawrence Livermore National Laboratory (LLNL), since 1998 on the Taiwan-America Occultation Survey (TAOS) project. This project is being succeeded by the Trans-Neptunian Automated Survey (TAOS II) which is under construction in 2012. To engage the larger optical facilities, the ASIAA participated in the Canada-France-Hawaii Telescope (CFHT) Widefield Infrared Camera (WIRCam) project in 2000 and the Spectropolarimetre Infra-Rouge (SPIROU) project in 2009. We also joined the Subaru Telescope HyperSuprime Cam (HSC) project in 2008 and the Prime Focus Spectrograph (PFS) project in 2011. These efforts led to the establishment of the Optical/Infrared Laboratory at ASIAA.

In the area of astrophysics theory, our Computational Fluid Dynamics/ Magnetohydrodynamics (CFD/MHD) group has been developing numerical computation capabilities at the ASIAA. This was followed by the establishment of the Theoretical Institute for Advanced Research in Astrophysics (TIARA) in 2004, which provides a coordinated program of research and education. TIARA regularly holds workshops and schools as well as international meetings. In 2012, the CFD/MHD group became the core members of our program on Computational Astrophysics.

The first three major ASIAA telescope projects — SMA, AMiBA, and TAOS — have all been brought into operations. The SMA was dedicated on Mauna Kea in Hawaii in November of 2003. Initial science results from the SMA were published in a special volume of the Astrophysical Journal in 2004. The SMA is now in regular science mode, featuring weekly remote operations from Taipei. The AMiBA was dedicated with seven elements on Mauna Loa in Hawaii in October of 2006. Science operations started in 2007, and the first seven science papers have been published in the Astrophysical Journal in 2009. In the same year, the upgrade of AMiBA to the 13-element configuration was completed, improving the speed by about a factor of 60. All four elements of the Taiwan-American Occultation Survey (TAOS) are operating on top of Lu-Lin Mountain since 2006. Five years of data have been accumulated, and the first science papers have been published in 2008. The system operates in fully automatic mode, with remote monitoring from ASIAA and NCU. In addition, ALMA has already begun Early Science operations in 2011, and the full array will be completed in 2013.

In terms of instrument developments for large optical telescopes, the WIRCam was completed and delivered in 2005, and the HSC was completed and delivered in 2012. Our efforts continue on the SPIROU and the PFS, with delivery in the 2015-2016 time frame.

For the on-going telescope projects, TAOS II will be constructed at the San Pedro de Martir Observatory in Mexico, and the first of three telescopes will be delivered in 2013. The GLT is currently being retrofitted for polar operations, and the site at the summit of Greenland is being developed. The GLT will work with the SMA and ALMA to provide interferometry at submillimeter wavelengths with intercontinental baselines. The GLT will also produce science in the unexplored Terahertz window. The GLT is scheduled to be placed into operations in 2015.

ASIAA aims to collaborate with the university groups in developing astronomical research in Taiwan. Collaboration with NCU has been underway for years through our partnership on the TAOS project. Collaboration with NTU has also been ongoing through our partnership on the AMiBA project. Collaboration with National Tsing Hua University (NTHU) has been ongoing in the fabrication of SIS junctions and on the TIARA project. In addition, ALMA includes participation from all the major universities in Taiwan.

ASIAA continues to collaborate with various international groups, including the Smithsonian Astrophysical Observatory (SAO) on SMA, TAOS, TAOS II, and GLT; the Australia Telescope National Facility (ATNF) and the Carnegie-Mellon University (CMU) on AMiBA; the National Radio Astronomy Observatory (NRAO) on AMiBA, ALMA, and GLT; the Jet Propulsion Laboratory (JPL) on AMiBA and PFS; the CFHT on WIRCam and SPIROU; the University of Pennsylvania (UPenn), LLNL, the Harvard-Smithsonian Center for Astrophysics, and the Yonsei University on TAOS; the Universidad Nacional Autónoma de México (UNAM) on TAOS II; the Nobeyama Radio Observatory (NRO) and the Purple Mountain Observatory (PMO) on SIS junction development; the National Astronomical Observatory of Japan (NAOJ) on ALMA, HSC, PFS, and SIS junctions.

The Astronomy-Mathematics Building Opening Ceremony on October 14 2011.

ASIAA is also a founding member of the East Asian Core Observatories Association (EACOA), together with the National Astronomical Observatory of Japan, the National Astronomical Observatories of China, and the Korea Astronomy and Space Science Institute. The EACOA promotes collaborations in East Asia, especially in the construction of future instruments.

ASIAA will continue to participate in the development of advanced astronomical instrumentation for research by the Taiwan astronomical community. The staff at ASIAA makes use of all the leading astronomical instruments in the world, and we aim at bringing this access to the astronomical community in Taiwan.

Former Academy President Yuan-Tseh Lee and current President Chi-Huey Wong in the the Astronomy-Mathematics Building Opening Ceremony.

Projects

Atacama Large Millimeter /Submillimeter Array

Since 2005 ASIAA has participated in the Atacama Large Millimeter/submillimeter Array (ALMA) project, the largest ground-based astronomical project ever carried out. The array is currently under construction on the Chajnantor plateau in the Atacama Desert in northern Chile, at an elevation of around 5,000 meters. ALMA will be completed in 2013, and its expected lifetime is at least 50 years. At present, more than half of the 66 ALMA radio antennas are already delivered to the Array.

Nineteen ALMA antennas on the Chajnantor plateau as of 2011 September.(Picture Credit: ALMA/ J. Guarda)

The ALMA project has three major international partners: North America, Europe, and East Asia. The North American and European partners are responsible for the construction of the 12m Array (ALMA-baseline project), while East Asia is responsible for the construction of the Atacama Compact Array (ACA; ALMA-Japan project). In September 2005, the Academia Sinica entered into an agreement with the National Institutes of Natural Sciences (NINS) of Japan to join the ALMA project through the ALMA-Japan project. In October 2008, the National Science Council (NSC) of Taiwan and the US National Science Foundation (NSF) reached an agreement for collaboration with ALMA-North America.

An aerial picture of the area where ALMA is being built. The 66 antennas of ALMA, when the construction is finished, will be able to be moved around the Chajnantor Plain up to a maximum distance of 16 kilometers between the furthest antennas. This overview provides a sense of the immensity of the plain. (Picture Credit: ALMA, W. Garnier; Acknowledgement: General Dynamics C4 Systems)

ALMA will cover the wavelength range from 0.3 to 10mm with an angular resolution of up to 4 milli-arcsec, producing 10 times sharper images than the Hubble Space Telescope. ALMA will be tremendously sensitive, and more than 10,000 times faster than any existing instrument at millimeter and sub-millimeter bands. With an unprecedented combination of sensitivity, angular resolution, spectral resolution and imaging fidelity at the shortest radio wavelength, ALMA is expected to make remarkably important contributions to a variety of scientific frontiers such as weather patterns on the solar system planets, the formation of planets and stars in our galaxy, the gas motions within active galactic nuclei, and the formation of the earliest galaxies at a redshift of z~10. In particular, ALMA will be a premier tool for capturing never-before seen details for the first stars and galaxies that emerged from the cosmic "dark ages" billions of years ago. Also, ALMA is expected to directly image young planets that are still in the process of developing.

The first round of scientific observations, known as ALMA Cycle 0 Early Science, started on 30th September 2011 with sixteen 12m antennas. Even under construction, ALMA has become the best telescope of its kind– as reflected by the extraordinary number of astronomers who requested to observe with ALMA. Out of around 900 applications from astronomers around the world, Taiwan succeeded in leading 8 of the 112 projects accepted.

After its month-long journey from Taiwan, the first of the two Front-End Service Vehicles is being tested at the ALMA Operations Support Facility in Chile. In this photo, the FESV cabin is raised to service the interior of a North American ALMA telescope. The first FESV is named Mei-hua after the Taiwanese plum blossom, a revered, winter-blooming flower.The second FESV is named Lan-que after the Formosan blue magpie. (Picture Credit: ALMA/Carlos Padilla)

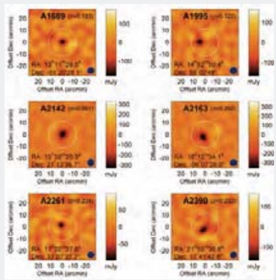
In addition to preparing for scientific projects for ALMA, we are also contributing to the construction of the array and associated engineering projects. Under collaboration with Aeronautical Research Laboratory, Chung Shan Institute of Science and Technology, ASIAA has established the East Asia Front-End Integration Center (EA FEIC). So far the Center has delivered twenty-two “front end systems” to Chile. The Taiwan team was also in charge of making two Front-End Service Vehicles (FESV) for the array. The FESV is a custom-designed truck which transports and services ALMA receivers which must be cooled to 4ºK (-269ºC) above absolute zero. It can be raised up to 6.5 meters high and work in severe high-altitude environment. The first Taiwan-made FESV, named Mei-hua (梅花), arrived in Chile in the end of August 2011 and entered service at the altitude of 5,000 meters. The second Taiwan-made FESV, named Lan-que (藍鵲), arrived in Chile in early December of 2011.

The Yuan-Tseh Lee Array for Microwave Background Anisotropy

The Yuan-Tseh Lee Array for Microwave Background Anisotropy (AMiBA) is a forefront instrument for research in the field of cosmology. It is an interferometer operating at 3mm wavelength to study arcminute-scale fluctuation in the cosmic microwave background (CMB) radiation. In addition to the primordial fluctuation, AMiBA can also detect perturbation to the CMB photons by galaxy clusters along the line of sight. The perturbation happens when hot electrons that reside in the deep gravitational potential scatter and transfer energy to the cold CMB photons. Such perturbation, called the Sunyaev-Zel'dovich effect (SZE), is directly related to the density and temperature of the hot gas, which traces the underlying dark matter distribution, and is complementary to information derived from X-ray, gravitational lensing, and kinematic observations of the galaxy cluster.

The first phase of AMiBA consisted of seven 0.6m antennas close-packed in the center of the 6m platform, offering a field-of-view of 23' and a resolution of 6'. Scientific observations were carried out during 2007–2008.

The AMiBA is situated on the slope of Mauna Loa at an altitude of 3,400 meters, on the Big island of Hawaii. The telescope was built and operated in two phases. The first phase comprises seven 0.6-meter antennas, with scientific observations during 2007-2008, and detection of six galaxy clusters in the redshift range of 0.09 to 0.32. The cleaned images of the clusters are shown to the right and the main results were published in 2009. The second phase includes expansion of the array to thirteen 1.2-meter antennas, enhancing the ability to detect clusters at higher redshifts.



Shown here are six galaxy clusters as seen by AMiBA at 3mm wavelength. Compared to the surrounding region, the center of the cluster is dimmer due to the SZ effect (Wu et al. 2009, ApJ, 694, 1619).

As the first major international astronomical project led by Taiwan, the AMiBA is also the first and the only CMB telescope for Asia. It has established experimental cosmology as a viable field in Taiwan. This project also produced a team capable of leading, designing, and building frontier instruments. Young students, engineers, and faculty, have been trained, cultivated, and mentored for Taiwan.

The second phase of AMiBA consisting of thirteen 1.2m antennas was completed in the end of 2009. The 13-element array, with improved resolution and sensitivity, can effectively study clusters that are much further away from us. Scientific operations resumed in 2011. The background shows another volcanic peak, Mauna Kea.

AMiBA is designed, constructed, and operated by ASIAA, with major collaborations with the Electrical Engineering and the Physics Departments of the National Taiwan University, and the Australia Telescope National Facility (ATNF). Additional contributions were also provided by the Carnegie Mellon University (CMU), the National Radio Astronomy Observatory (NRAO), and the Jet Propulsion Laboratory (JPL). The construction of AMiBA includes a novel hexapod mount, a carbon fiber platform, carbon fiber reflectors, low-noise receivers, a broadband correlator, sensitive and stable electronics, a retractable cover, site infrastructures, and software development.

The project completed the design study of AMiBA (2001-2002), fielded a 2-element prototype on Mauna Loa (2002), contracted and constructed all components (2002-2005), secured and developed the site on Mauna Loa (2004), took delivery of all components (2005), and integrated and commissioned the system (2006). In October 2006 the seven-element system was dedicated to the then President of Academia Sinica Yuan-Tseh Lee for his continued support of the project.

Science operations began in 2007, and 22 papers have been published or in press between 2009 and August 2012.The 13-element 1.2-meter expansion was completed in June 2009, which was followed by periods of intense re-commissioning to meet the more stringent requirements. The new array is shown to be 8 times more sensitive for point sources, increasing the observation speed by a factor of 60. Routine science operation has resumed in 2011.

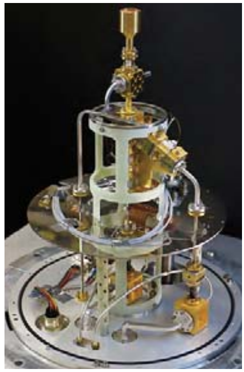
In April 2007, we detected the first SZE signal with the 7-element AMiBA towards the galaxy cluster A2142 at a redshift of z=0.091, followed by successful SZE detections towards five more clusters ranging from z=0.18 to 0.32. The primary efforts were in the areas of calibration and data reduction, identifying and flagging of bad data, removal of systematic errors, elimination of foreground contamination from the local environment, converting output from the lag correlator into u, v data points, fourier transform of the visibilities, and compensation for poor u, v sampling or dirty beam pattern. Much effort was devoted to verifying the quality of the data. This involved analysis of the noise characteristics of the data, evaluating the contamination from CMB structures, and compensating for expected point sources in the field of view. (Ho et al., 2009, ApJ, 694, 1610; Lin et al. 2009, ApJ, 694, 1629; Nishioka et al. 2009, ApJ, 694, 1637 ; Liu et al., 2010, ApJ, 720, 608)

While the SZE is suitable to probe the extent of hot gas, the weak gravitational lensing (WL) effect is ideal to measure the large scale distribution of dark matter. Comparison of the two data sets can reveal how gas mass fraction varies with the cluster radius, which can constrain the formation mechanism of the galaxy clusters. We have WL data for four of the clusters detected by AMiBA. The averaged result from the comparison of SZ and WL data is shown in a figure on the next page.

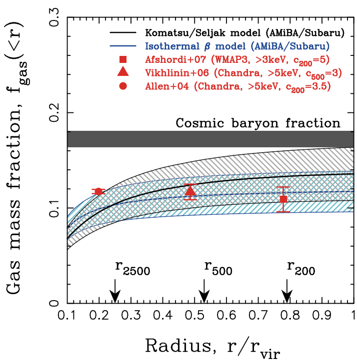
AMiBA was dedicated in October 2006. The two panels show the gathering of team members, and the Academy President Yuan-Tseh Lee at the dedication ceremony.

Among our sample, the cluster Abell 2142 is of particular interest since this is our brightest, most-nearby (hence resolvable) SZE cluster at z=0.09, known as a merging cluster. Our AMiBA SZE map shows an elliptical structure extending in the northwest (NW) - southeast (SE) direction, similar to the shape of the weak lensing (dark matter) distribution. This extended nature of almost 20 arcmin in length from NW to SE is one of the reasons why sampling with the small antennas of 0.6m can be important for providing sensitivity to large scale structures.

Other science cases include the comparison of SZE with X-ray data in order to derive cluster angular diameter distances and the Hubble constant, cluster scaling relations, and a study of cluster gas properties as constrained by the 13-element AMiBA. These early science experiments served to demonstrate the potential and performance of AMiBA. (Huang et al., 2010, ApJ, 716, 758; Liao et al., 2010, ApJ, 713, 584; Molnar et al., 2010, ApJ, 723, 1272; Koch et al., 2012, ApJ, Submitted)



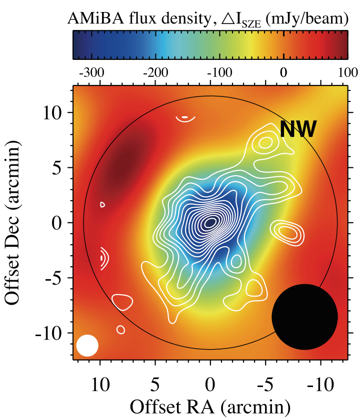
The AMiBA receiver with the vacuum chamber removed (Chen et al. 2009, ApJ, 694, 1664).



Combined with Subaru weak lensing measurements, the AMiBA SZE data can be used to derive gas mass fraction as a function of cluster radius (Umetsu et al. 2009, ApJ, 694, 1643).

A 2-element prototype system was tested on the Mauna Loa site from 2002 to 2004.

The ground breaking of the AMiBA site follows a traditional Hawaiian ceremony in April 2004.



The Subaru weak lensing mass map (white contour) is overlaid on top of the AMiBA SZE measurement (color map) for the cluster Abell 2142. The open and filled black circles respectively for AMiBA. The filled white circle represents the resolution of the weak lensing data. This map shows that hot gas as seen in both SZE and the dark matter, traces an elongated distribution in the NW-SE direction (Ho et al. 2009, ApJ, 694, 1610).

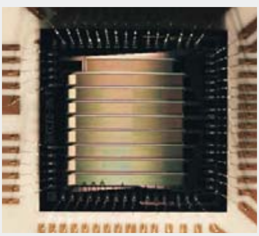
The hexapod mount was installed and tested in early 2005.

Canada-France-Hawaii Telescope(CFHT) Collaboration

The optical and infrared instrumentation program of ASIAA started with the development of the Wide Field Infrared Camera (WIRCam) for the 3.6-meter Canada-France-Hawaii telescope (CFHT). The WIRCam project officially started in late 2001. This camera has four 2,048×2,048 HAWAII-2RG HgCdTe detector arrays, with a 20' field of view, and 0.3″ pixel resolution. The camera optics are cooled to liquid nitrogen temperatures to suppress the infrared background. With the on-chip guiding capability of the IR array, the camera provides a 50Hz tip-tilt correction and micro-dithering observations. In 2005, the WIRCam was installed and commissioned on CFHT. The camera has been fully functional for scientific observations since then without any major failure. The limiting magnitude in Ks band for a 10 sigma detection in a 1 hour exposure under 0.7 arcsecond seeing is about 23.1 in AB magnitude.

Left: The WIRCam was completed and installed on the CFHT during 2005. Right: The Orion nebula image taken by WIRCam.

In this project, the ASIAA staff was heavily involved in the development of the array control electronics and the real time image analysis. We also participated in the system definition and final integration of the camera. Furthermore, we contributed major effort in upgrading the official data pipeline. With the delivery of WIRCam, ASIAA continues its instrumentation collaboration with CFHT on the development of CCD curvature wavefront sensor “FlyEyes”. The main goal of this project is to evaluate and characterize the MIT CCID-35 detector as a suitable replacement for the avalanche photo diode modules (APDs) in the existent curvature wavefront sensor. ASIAA mainly contributed to the hardware interface definition, detector controller system software design, CCD characterization, and AO system simulation.



Left: The MIT CCID-35 chip. Right: Image of a Mag 8.1 star with AO off and on with FlyEyes.

Participants of CFHT users meeting in ASIAA in November 2010.

CFHT started to plan on the next generation instruments in 2009. ASIAA joined the Spectropolarimètre Infra-Rouge (SPIROU) project which is a high resolution infrared spectropolarimeter. SPIROU was then selected as the top-ranked instrument to be developed for the next few years on CFHT. The major science goal for SPIROU is to detect the exo-planets in the habitable zone, i.e. to detect planets at the right distances from M dwarf stars. In order to detect such planets, the radial velocity accuracy for SPIROU is targeted to be 1m/s. This requires very precise control of machinery, temperature and optical path. Also, SPIROU will be a powerful tool for the study of magnetic fields in young stellar objects and protostars.

SPIROU consists of two major components: the Cassegrain model and the spectrometer connected by optical fibers. SPIROU will have a large cryogenic spectrometer with precise temperature control to ensure the stability of the spectrum. The spectrum from 0.95 to 2.4μm will be recorded by the advanced HAWAII-4RG detector in single exposure. The development team includes several labs in France (Toulouse, Grenoble, and Marseille), University of Montreal, Hertzburg Institute of Astronomy, Observatory of Geneva, CFHT, and ASIAA. We will be responsible for the delivery of the tip-tilt camera and the viewing camera. The tip-tilt camera will provide 100Hz images of target stars with a centroid measurement better than 0.02". The viewing camera will be used to guide the target star to the fiber pickup surface and monitor the relative motion between the target star and the fiber. Ultra low readout noise (< 3e-) is required for the tip-tilt and the viewing cameras to achieve the image stability and thus the radial velocity accuracy. The project is now in phase B and is expected to see the first light in 2015.

For science activities, Taiwanese astronomers share around 15 nights of CFHT observations every year since 2004. Every semester, the proposals from Taiwanese astronomers are reviewed by external referees and then ranked by the local time allocation committee. As a general facility of the astronomical community, various scientific topics have been observed with CFHT from solar system, star formation, to Galactic study, large structure and cosmological studies. In particular, many ASIAA proposals focused on high redshift and large scale studies. CFHT time provides great opportunities for the students to access a world-class telescope, which is important for development of the next generation of astronomers in Taiwan.

This collaboration also enhances the communications between astronomers in Taiwan and those in Canada, France and Hawaii. In particular, ASIAA held the CFHT user meeting in 2010 with more than 100 participants from around the world. This is the first time for CFHT users meeting to be held outside of Canada or France. The meeting provides the chance for Taiwanese astronomers to know more about the science done with CFHT and to establish collaborations on scientific topics with other users. The participation in large programs with other CFHT users provides the opportunity for us to access large CFHT databases and to work with experts in the world.

The SAO/ASIAA Submillimeter Array

Since 1996, ASIAA has been carrying out the Submillimeter Array (SMA) project in collaboration with the Smithsonian Astrophysical Observatory (SAO). The array was dedicated on Mauna Kea, Hawaii in November 2003 by the then Academia Sinica President Yuan-Tseh Lee and Smithsonian Institution Secretary Larry Small. It is a radio interferometer consisting of eight 6-meter antennas, with two of them (including the associated electronics and receiver systems) delivered by ASIAA under close collaborations with university groups and industry in Taiwan. It operates at 230, 345, 400, and 690GHz. It can be arranged into configurations with baselines as long as 509 meters, allowing us to observe submillimeter emission from warm, dense gas and dust at unprecedented high resolutions of up to 0.1 arcsecond. Each element can observe up to 4GHz bandwidth. The digital correlator backend provides thousands of spectral channels to each receiver. The research fields include the Solar system, star and planet forming regions, evolved stars, and galaxies at nearby and cosmological distances. As of August 2012, 428 SMA papers have been produced. Of those, 86 papers have first authors from ASIAA, and 185 papers have co-authors.

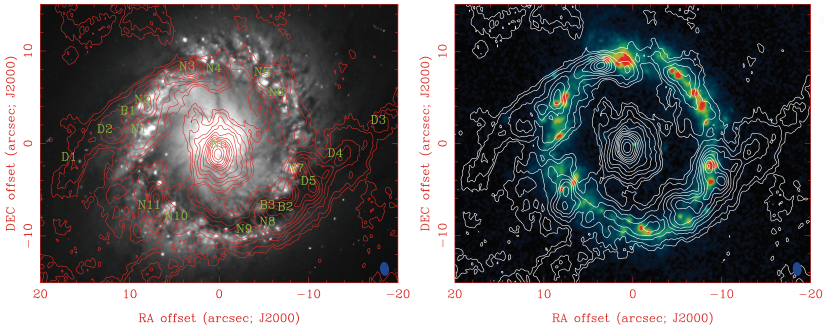
The two SMA antennas built in Taiwan.
(Picture Credit : Ming-Tang Chen)

As a partner of the SMA project, ASIAA contributes towards the maintenance and operation of the array on Mauna Kea. ASIAA has a small local staff residing in Hilo, Hawaii. In addition, the scientific and engineering staffs visit the site regularly, and conduct remote operations from Taipei.

The SMA, built at the top of Mauna Kea at an altitude about 4,000 meters in Hawaii. (Picture Credit: Derek Kubo)

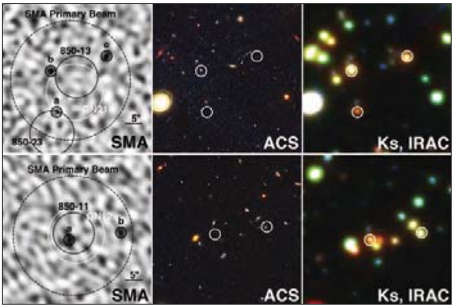
Scientific Highlights with the SMA

The SMA has been playing an important role in studying extragalactic objects. One of our targets is the Seyfert 1/ starburst ring galaxy NGC 1097. The CO(2-1) image at 1.5"x1.0" (105x70pc) resolution shows a central concentration and a ring-like structure at a radius of ~10" (700pc). The high-resolution map obtained with the SMA for the first time resolves the molecular ring into individual clumps at the giant molecular association (GMA) scale of 200 to 300pc. The morphology of the molecular gas is tightly correlated to the optical features.



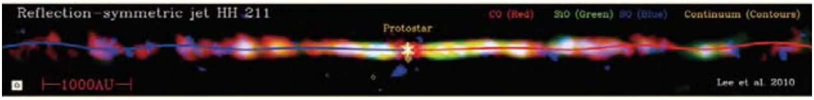
Left : CO(J = 2-1) integrated map (contours) overlaid on the archival HST I-band image (black & white).
Right : HST NICMOS Paα line image (color) overlaid on the CO(J = 2-1) contours (Hsieh et al. 2011, ApJ, 736,129).

In addition to nearby galaxies, distant galaxies can be studied using the SMA as well. The wide bandwidth of the SMA allows us to image faint dusty galaxies in the high-z universe. The SMA, for the first time, resolved the submillimeter sources into multiple submillimeter galaxies at high redshifts. This indicates either some unusual clustering properties of submillimeter galaxies, or a larger number of faint submillimeter galaxies than previously thought.



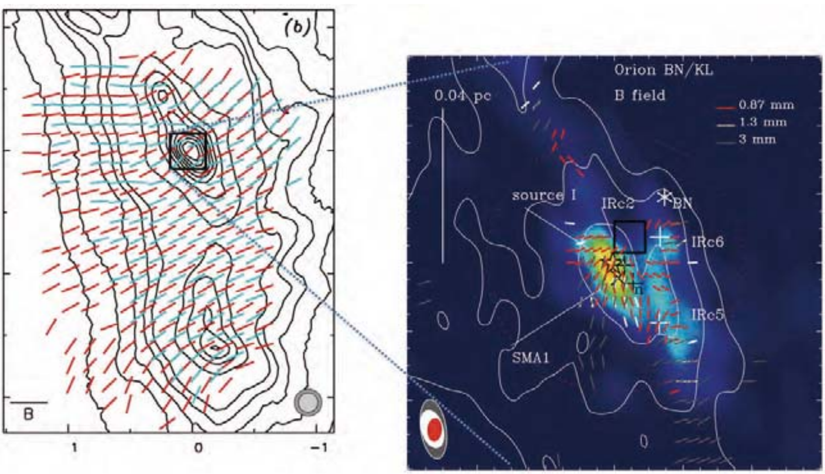
Submillimeter galaxies GOODS 850–23 (top) and GOODS 850–13 (bottom). Left: 0.88mm images observed with the SMA. Middle: Optical images observed with the HST. Right: Infrared images observed with CFHT Ks (blue) and Spitzer IRAC (green and red). Small solid circles in all panels indicate the SMA sources (Wang et al. 2011, ApJ, 726, L18).

The SMA is a very powerful tool for studying star and planet forming regions. A variety of observational projects have been carried out in ASIAA. In the earliest phase of star formation, gas and dust are seen ejected supersonically from protostars, forming bipolar jets such as that seen in HH211. The jet is clearly seen on both sides of the source with more than one cycle of wiggle. The wiggle is reflection-symmetric about the central exciting source and can be reasonably fitted by a jet source which is part of a binary orbiting system. The dust continuum emission in the central disk is spatially resolved into two objects, with the brighter one associated with the source that drives the jet.



The HH211 molecular jet imaged with the SMA at 0.3" resolution. The CO, SiO, SO, and 0.85mm continuum are red, green, blue, and orange (contours), respectively (Lee et al. 2010, ApJ, 713, 731).

Magnetic fields play an important role in star formation, and the SMA can be used to infer their detailed distribution in star-forming regions by observing the polarized dust continuum emission at high angular resolution. Figure below shows the magnetic fields in OMC1, which is a molecular cloud behind the Orion M42 nebula. The large scale magnetic fields in OMC1 are uniform and perpendicular to the dust emission ridge. On the other hand, if we zoom in to the most prominent peak called Orion BN/KL, the magnetic fields start to show azimuthally symmetric structure. The field directions are pointing toward 2.5" west of the center of explosive outflows, indicating that the pattern of the magnetic field may be shaped by the outflows.



Left: Maps of magnetic field in the OMC1 region as observed with the CSO at 0.35mm (red) and 0.45mm (blue). Continuum intensity at 0.35mm is shown as black contours. Right: Maps of magnetic field in the Orion BN/KL region as observed with the SMA at 0.87mm (red) and with the BIMA at 1.3mm (white) and 3mm (grey). Continuum emission at 0.87mm is shown in both contours and color scale (Tang et al. 2010, ApJ, 717, 1262). The black square marks the location of an explosive outflow which has been seen in CO.

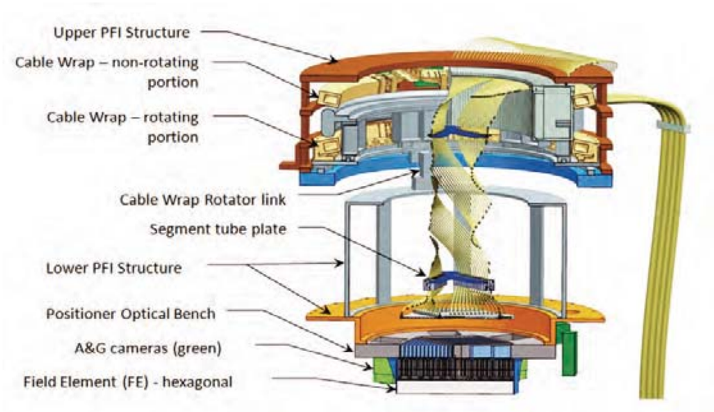
Subaru Telescope Collaboration

In order to gain access to larger aperture telescopes, ASIAA started to work with the Subaru telescope in 2008. ASIAA contributes to the wide-field camera at optical wavelengths called the Hyper SuprimeCam (HSC). HSC is the next generation instrument for the Subaru telescope which provides a 1.5 degree FOV with superb efficiency and image quality at the red end of the visible region. HSC is a collaboration between the National Astronomical Observatory of Japan (NAOJ), Princeton University and ASIAA. Combined with the 8.2m aperture, HSC will be the most powerful imaging camera in the world until the Large Synoptic Survey Telescope (LSST) comes on line. The camera will deliver a superior performance as compared with the SuprimeCam and with a 10 times larger FOV. With the newly developed fully depleted CCDs, HSC is expected to provide 40% higher overall throughput in z' band and provide reasonable efficiency in Y band.

The HSC installed on the Subaru telescope (top) with the FES attached (bottom).

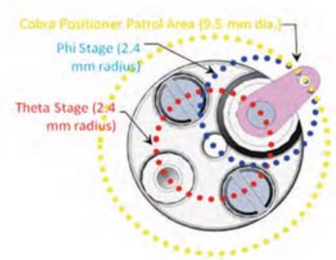
The challenge of developing HSC is to overcome the space and weight limit allowed at the prime focus of the Subaru telescope. In the development of HSC, NAOJ manages the project and develops the CCD integration, camera dewar and electronic system. Mitsubishi Electronics and Canon are responsible for the mechanical and optical system. ASIAA is responsible for the delivery of the filter exchanger system (FES), the testing system of the wide field correctors (WFC) with Canon, and the testing of some of the CCD chips. The FES is developed with the collaboration with the Aeronautical Systems Research Division (ASRD) of the Chung-shan Institute of Science and Technology (CSIST). Due to the space limit, FES of HSC is designed to be a robotic system attached to the outside of the camera body. FES delivers the filters over a distance of 1.5m to the optical axis with a precision of 50μm. 6 filters can be installed at one time for the HSC observations. FES was delivered to Japan in May 2011 for the system integration and testing. The lens testing system was completed and used for the WFC tests from early 2011. This project further enhanced our instrumental capabilities and provided a unique chance to work with the new generation of CCDs. All subsystems of HSC were delivered to Hawaii in late 2011 for the final integration. We expect to see the first light of HSC in late 2012.

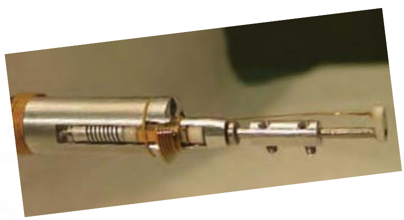
With the HSC close to completion, we continue to work with the Subaru telescope for developing the next instrument. To complement the capability of HSC, Japan has decided in 2010 to develop the multiple objects spectrograph at the prime focus of the Subaru telescope. The design of the Prime Focus spectrometer (PFS) is based on the WFMOS project originally proposed for the Gemini telescope. PFS will have 2,400 fibers which can be independently positioned within a 1.5 degree field. Each fiber will guide the light of a target to four identical spectrometers which generate the spectra from 400~1,300nm with a resolution of about 4,000. The Institute for the Physics and Mathematics of the Universe (IPMU) of Tokyo University is leading the project. Other partners include Caltech/JPL, Laboratoire d'Astrophysique de Marseille (LAM), Princeton University, John Hopkins University, National Astrophysical Laboratory (LNA) of Brazil, NAOJ and ASIAA.



The Prime Focus Instrument of PFS.

PFS and HSC share the same wide field corrector. Prime focus instrument, fibers and spectrometers are the three major components for PFS. The major challenge of PFS is the driving mechanism of the fibers to match the targets within 0.1” error in 40s. During the WFMOS development, JPL has been working with New Scale Technology Co. to develop miniature motors. Each fiber will be driven by the two stage rotary piezoelectric motors. The fiber can be moved to any location within the 9mm working area of the motor without an absolute encoder. A delicate metrology camera is designed to provide precise location information (within 3 microns) of the fibers. Caltech/JPL will be responsible to deliver the fiber positioners while ASIAA will be responsible for the metrology camera and the construction of the PFI structure. LNA will provide the fibers connecting the prime focus with the spectrometers located outside of the observing floor. LAM will develop the spectrometers while Princeton and John Hopkins will deliver the cameras for them. We are now developing a metrology camera for FMOS which is the existing multiobject spectrometer on Subaru. This camera will be a prototype camera for PFS and we plan to finish the metrology camera for PFS in 2013, and the PFI structure in 2014.



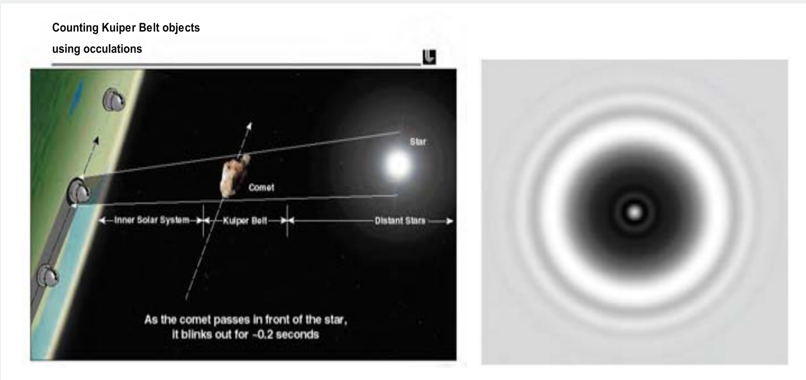


The possible patrolled area for the miniature motors of PFS.

PFS successfully completed the conceptual design review in early 2012 and the team will deliver a prototype system in early 2014. The whole project will be finished in 2016. PFS will be open to the Subaru users but a large survey is also planned for the Baryon Acoustic Oscillation study for the development team. Taiwanese astronomers will be involved in the project.

The Taiwan-America Occultation Survey (TAOS)

TAOS is a collaboration consisting of ASIAA, the National Central University (NCU), the Harvard-Smithsonian Center for Astrophysics (CfA), and the Yonsei University in Korea. The survey aims at detecting occultations of distant stars by small (1km diameter) Kuiper Belt Objects (KBOs). This survey presents several cchallenges. In particular, such events have a very short duration, typically less than 200ms. Detection is further complicated by the fact that the sizes of the objects we are searching for lie in the Fresnel regime, and the events thus show significant diffraction effects (see the figure below).



Left panel: An occultation event occurs when a KBO passes between the telescope and a distant star.
Right panel: Shadow of a KBO projected onto the surface of the Earth. Note the significant diffraction effects. The image is 10km on a side.

TAOS operates four 50cm robotic telescopes at Lu-Lin Observatory in central Taiwan (next figure). Each telescope is equipped with a 2k×2k CCD camera, with which we read out the images with a cadence of 5Hz. We thus monitor 500 to 1,000 stars simultaneously with all four telescopes to search for coincidental flux variations that are consistent with occultations by KBOs. TAOS is also sensitive to more distant objects up to 1,000AU, which are beyond the reach of any telescope using direct detection of reflected sunlight. The discovery of Sedna implies the existence of a hitherto unknown population of objects beyond 100AU, which are too distant to be perturbed by any known planets at their present positions.

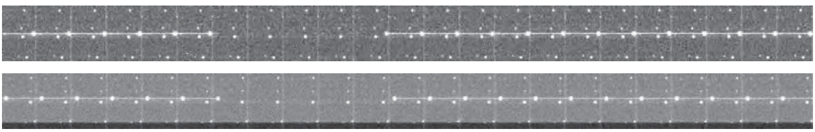
The estimated KBO occultation rate is extremely low and highly uncertain. Predicted rates range from 0.01 to 100 events per year. Given that we make as many as several billion photometric measurements per year on a single telescope, special care must be taken to minimize the rate of false positive events. We thus require coincident detection of any event on all four telescopes. This criterion keeps our false positive rate below 0.1 event per year.

One of the TAOS 0.5m telescopes in its enclosure.

The four TAOS telescopes on top of Lu-Lin Mountain.

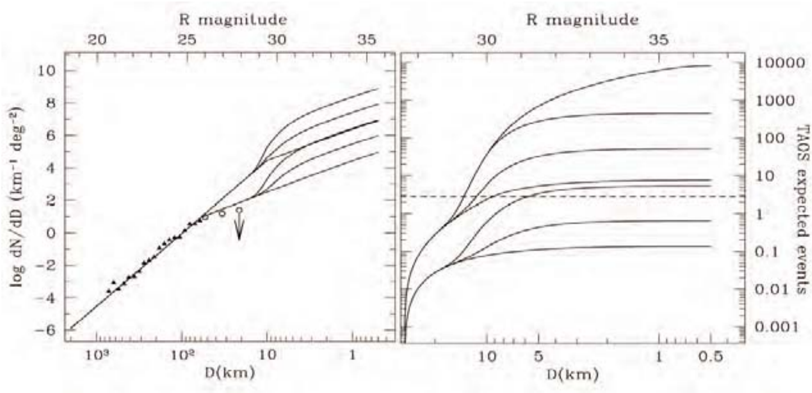
We began the survey using only three telescopes in February 2005, and four-telescope operations commenced in August 2008. To date we have collected over 10 billion three-telescope photometric measurements and more than 3 billion measurements with all four telescopes. The system operates in fully automatic mode, with remote monitoring from ASIAA and NCU.

A test of the system was carried out in June 2004 when a star of 8.5-mag. was occulted by an asteroid of 15.5-mag. (#1723 Klemola with diameter 31km). Two TAOS telescopes successfully detected this event with better than 0.25 second time resolution under remote control (see figure below).



TAOS images (two telescopes) of the occultation of HIP050525 (m_V~8.46) by the asteroid (1723) Klemola (m_V~15.7; D~31km). Each frame is a 0.25 second read out of the field (time increases to the right.) Some 10^{10} stellar photometric measurements have now been made in this mode.

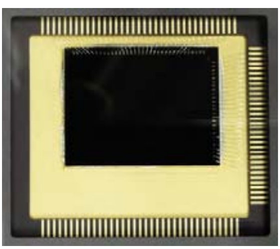
The team has analyzed all of the three-telescope data through August 2008. No candidate events were found, and TAOS has placed the strongest upper limits on the size distribution of objects with 0.5km < D < 28km that have been published to date. (The TAOS limits are an improvement of a factor of three over the most recently-published limits.) Furthermore, TAOS is exploring several different models of the formation of the Kuiper Belt. Given that no events were found, we can exclude at the 95% confidence level any theoretical model which predicts that TAOS would have detected three or more events. This is illustrated in the next figure, where some example models of the size distribution are shown. These models predict anywhere from a few to a few thousand events to be detected by TAOS. This shows that TAOS is capable of probing a significant amount of parameter space, and continued operation will allow us to place even more stringent constraints on these models in the future. TAOS has now collected three times as much data since the results displayed above were published. The results were published in the spring of 2012.



Left panel: A series of models of the size distribution of the Kuiper Belt objects published by Kenyon & Bromley, 2004, AJ, 128, 1916. Points represent measurements of size distribution from direct observations. Right panel: The cumulative number of expected events from the TAOS survey for the models in the left panel. Any model which predicts more than three events is excluded at 95% confidence level.

Currently, the Trans-Neptunian Automated Occultation Survey (TAOS II), a successor survey to TAOS, is under construction. The design goal of TAOS II is a factor of 100 improvement in the event rate over TAOS. This will be achieved by using larger telescopes, a higher imaging cadence (20Hz), and a better site. The collaboration will install three 1.3m F/4 telescopes at San Pedro Mártir Observatory in Baja California, México, and equip each telescope with a custom camera, each consisting of an array of fast readout CMOS chips (see figure below). The camera is being developed in collaboration with CfA. The new CMOS sensors will allow readout of as many as 10,000 stars simultaneously at a cadence of 20Hz. Given the improvements over TAOS and the vast quantity of data we expect to collect, TAOS II should be capable of probing the entire parameter space predicted by models of the size distribution. Furthermore, given the higher readout speed, TAOS II will be able to resolve the diffraction fringes in the occultation shadow, which will allow us to make estimates of the sizes and distances of any detected objects. We expect TAOS II to start collecting data in 2014, and we plan to run the survey for a total of four years.

ASIAA is collaborating on TAOS II with Universidad Nacional Autónomia de México (UNAM), who will develop the site. We are currently in the process of obtaining the necessary environmental and building permits, and construction of the site will begin in 2012.



The prototype CMOS sensor picture for the future TAOS large format sensor.

A 1.3m telescope, similar to the model to be used in TAOS II.

Theoretical Institute for Advanced Research in Astrophysics

The Theoretical Institute for Advanced Research in Astrophysics (TIARA) was established in 2004 to provide an integrated world-class program of research and education in theoretical astrophysics. The institute aims at coordinating efforts of researchers and the training of future theoretical astrophysicists throughout Taiwan and Asia. It serves as an international center of excellence where forefront research can be intimately integrated into the graduate education at Taiwan's universities and academic institutions. It has facilities located at the Academia Sinica Institute of Astronomy and Astrophysics in Taipei and on the campus of National Tsing Hua University in Hsinchu.

TIARA's mission involves the investigation of the astrophysical processes associated with the formation of structure in the universe. Current research activities span star and planet formation, evolved stars, galactic structure and dynamics, accretion phenomena, and high energy astrophysics including compact objects. To keep scientists in Taiwan current with developments in the field and to inform the international community of the developments in Taiwan, TIARA runs an active visitors program and organizes and hosts a vigorous series of topical workshops on especially timely areas. TIARA has hosted workshops focusing on special topics in star formation, high energy astrophysics and compact objects, and cosmology. Depending on the scale of the workshop, the participants ranged from ten to twenty international experts and those from the local community. These workshops have been very successful in facilitating the exchange of scientific ideas and numerous papers have been produced which acknowledge the activities hosted by TIARA. In addition to the workshops, TIARA played a major role in the organization and hosting of the bi-annual East Asian Numerical Astrophysics meeting (EANAM 2010) in Taipei. The meeting attracted a record-breaking attendance making it the largest of all such meetings. Of particular importance was the participation of a large number of students primarily from the East Asian region, which made it the most successful meeting in the series.

TIARA is also playing a major role in improving the graduate education of students at universities throughout Asia by holding schools on special topics in Taiwan. The schools are geared towards college and university students as well as young postdoctoral researchers who wish to deepen their knowledge or branch out into a new area. These schools offer intensive, in depth courses over a one-week period to allow a complete pedagogical approach starting from fundamental theory to advanced applications in confronting current observational facts. There have been seven successful winter schools since TIARA’s inception. In this past year, the first TIARA summer school was offered focusing on star formation. These schools last for one week with lectures delivered by invited speakers from throughout the world and within Taiwan as well. We have successfully attracted over 40 students from East Asian regions including Taiwan, China, Japan, and Korea as well as from Europe. The students also interact with one another via the student presentations, which are part of the winter school program as well.

Currently, seven research fellows, four visiting research fellows and three post-doctoral research fellows are in residence in TIARA, with over twenty other scientists visiting on a short term basis per year. Two adjunct research fellows are in Academia Sinica and eight members are in local universities. In the future, plans are underway to develop collaborative programs with potential partner universities in China and with the University of California in the United States.

TIARA Workshop "Star Formation through Spectroimaging at High Angular Resolution" held at ASIAA in 2011 June.

TIARA Workshop on the Transient Universe at National Tsing-Hua University in 2011 December.

Star Formation Summer School at ASIAA in 2011 June.

TIARA 2012 Winter School on Galaxy Formation at ASIAA.

Very Long Baseline Interferometry

The submillimeter wavelength very long baseline interferometry (VLBI) project is a pioneering program dedicated to the pursuit of the highest angular resolution. As the angular resolution of interferometry is proportional to λ/D, where λ is the observing wavelength and D is the length of the baseline between two telescopes, observations at shorter wavelengths and/or longer baselines are essential to attain a higher angular resolution. By the combination of submillimeter wavelengths and intercontinental baselines, Submillimeter (submm) VLBI will achieve the resolution of several tens of micro arcseconds.

With such high angular resolution, we aim at imaging the shadow of a super massive black hole (SMBH). The shadow image will give us a direct clue for the existence of the black hole. Furthermore, the image of the immediate environment of a SMBH will provide us a new window for studying General Relativity under a strong gravitational field. Tentative goals of this project are to image the shadow of the SMBH and the connection to the innermost part of the jet and accretion disk. Imaging the SMBH will measure the mass and spin parameters of the SMBH. Imaging the jet and accretion disk will allow us to investigate the launching mechanisms of the ultra-relativistic jets and the accretion process onto the SMBH.

Submm VLBI observations are conducted under international collaborations. We are planning to play a leading role in the observations by proposing a new submm VLBI array consisting of the Submillimeter Array (SMA) in Hawaii, the Atacama Large Millimeter/submillimeter Array (ALMA) in Chile, and a new telescope at an excellent site.

The new telescope is a prototype ALMA telescope, 12 meters in diameter, designed for mm and submm wavelengths (0.3 to 10mm, or 30 to 950GHz). This telescope is currently located at the Jansky Very Large Array (JVLA) site of NRAO in New Mexico. In July 2010, the US National Science Foundation (NSF) announced a call for expression of interests for this telescope. The collaboration led by ASIAA, with CfA, MIT Haystack Observatory and NRAO as partners, was awarded the telescope in April 2011. We have started to retrofit the telescope for operations at low temperatures.

Expected image of the black hole shadow by the ray tracing method. (Picture Credit: Avery E. Broderick)

We have examined a few possible sites for submm observations, comparable to those of the ALMA, the SMA, and the South Pole Telescope (SPT). Based upon the precipitable water vapor (PWV) data measured by the NASA satellites Aqua and Terra/MODIS, we found that the summit in Greenland shows PWV<3mm throughout the year. For further evaluation, we started site testing at summit station in Greenland by installing a radiometer to measure the transparency at a submm wavelength. Current data suggest median PWV ≤0.9mm in the winter across 2011 and 2012. The project is currently working with the NSF Office of Polar Programs to acquire a site in Greenland and to deploy the ALMA prototype telescope as the Greenland Telescope around 2015.

The ALMA-NA prototype telescope at Socorro, New Mexico, with one of the JVLA antennas.

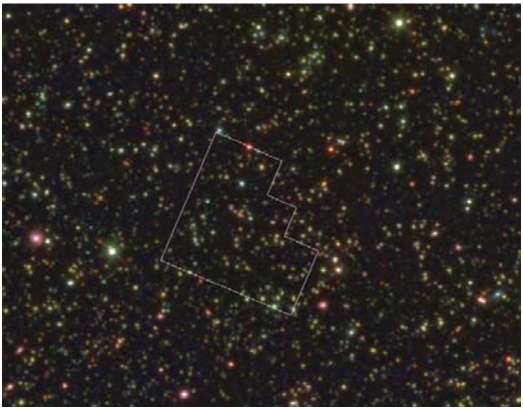
Our radiometer deployed at the Summit Camp in Greenland.

Scientific Highlights

Extragalactic Studies

An Infrared Survey in the Hubble Deep Field

Wei-Hao Wang and his collaborators had carried out a deep near-infrared imaging survey in the famous Hubble Deep Field-North (HDF-N) and its surrounding region. The survey utilizes the Wide-field Infrared Camera (WIRCam) on the 4m Canada-France-Hawaii Telescope on Mauna Kea. The imaging survey was performed at 2.1 micron, the longest near-infrared wavelength that can be efficiently observed from the ground. The mosaic image covers a 0.5×0.5deg^2 field (see figure below). A total of nearly one hundred thousands of galaxies are detected, to a limiting AB magnitude of 24.5, which is as deep as the Spitzer Space Telescope images at longer wavelengths. This is the deepest near-infrared image ever made over such a wide field, and this provides a rich database for the studies of galaxy formation and evolution in the distant universe. The image and galaxy catalogs were publicly released to the astronomical community, so researchers all over the world can use our data for their studies. This work is published in Wang et al., 2010, ApJS, 187, 251.

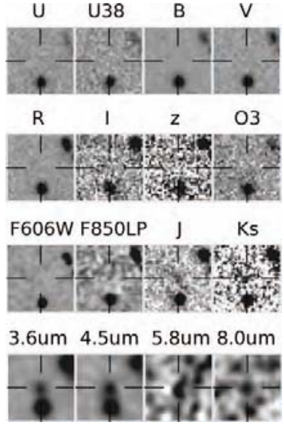


A near-infrared picture of the Hubble Deep Field-North. In this tricolor picture, red represents data from the Spitzer Space Telescope at 5.8 and 8.0 micron, green represents data from Spitzer at 4.5 and 3.6 micron, and blue represents data from our ground-based 2.1 micron observations. Except for a few stars, every single fuzzy dot in this image is a galaxy in the distant universe. The extremely rich colors of galaxies in this picture indicate a very broad range of physical properties of the galaxies, including their distance, stellar age, and star formation activity. The white polygon in the center is the famous Hubble Deep Field-North observed by the Hubble Space Telescope. The area in this picture only represents roughly 6% of the total area of our observations.

Finding the oldest galaxies

Observing very high redshift objects is fundamentally important in astrophysics. By doing so, one is expanding the observations to new frontiers and getting closer to understanding the formation of the first galaxies black holes. Bau-Ching Hsieh and his collaborators initiated the Taiwan ECDFS Near-Infrared Survey (TENIS). The primary goal of TENIS is to find well-screened galaxy candidates at z>7 in the Extended Chandra Deep Field-South (ECDFS). To this end, TENIS provides relatively deep J (1.2 micron) and Ks (2.1 micron) data (limiting magnitude reaching 25.5 AB) for an area of 0.25deg^2 ,which are obtained using the WIRCam on the 4m CFHT on Mauna Kea. The well-established Lyman-break technique is used to identify the strong high-redshift intergalactic medium absorption shortward of the Lyman-α wavelength that produces a steep color break (or dropout) between two adjacent filter bands. For z>7, this is the z-J color break (or z-dropout).

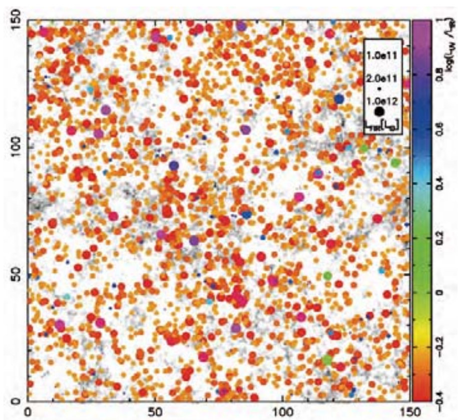
Illustrating the effectiveness at which we can screen out interlopers, we find only one z>7 candidate, TENIS-ZD1 (see figure to the right). The candidate has a weighted photometric redshift of 7.8, and its colors and luminosity indicate a young (64 million years old) starburst galaxy with a stellar mass of $6.2\times10^{10} M_\odot$. This result matches with the observational luminosity function analysis and the semi-analytic simulation result based on the Millennium Simulation. The cosmological parameters used in the Millennium Simulation, however, are different from the most recent WMAP7 estimation, resulting in an over-prediction of the volume density for high-z massive galaxies. The existence of TENIS-ZD1, if confirmed spectroscopically to be at z>7, would therefore pose a challenge to current theoretical models for how so much mass can accumulate in a galaxy at such a high redshift. Indeed, until the next generation of space or ground-based optical/near-IR telescopes become available, galaxies such as TENIS-ZD1 will provide the greatest leverage for testing models of galaxy formation and evolution. The results of this study have been presented in Hsieh et al., 2012, ApJ, 749, 88.



Thumbnail images for TENIS-ZD1 (each frame is 10 arcsec on a side). TENIS-ZD1 is not detected in all the optical bands (from U to F850LP) but is detected in all the bands redder than 1.2 micron, which suggests that it is a galaxy at z>7.

Simulation of galaxy evolution for ALMA

There are billions of billions of galaxies in the Universe, and they are not uniformly distributed in space. Rather they are "clustered"; that is, they tend to form large structures in the Universe. The optical (and near infrared in the frame of the observers) astronomers have found large scale structures of galaxies up to redshift of 7. This means that the galaxies have already formed in the first several hundreds of million years in the history of the Universe. Because dust in galaxies absorbs the optical stellar light and re-emits it in the far infrared and submillimeter wavelengths and, perhaps more importantly, dust traces the metal enrichment in galaxies and becomes ingredients for planets, our understanding of early galaxy formation would not be complete without observing in the far infrared and submillimeter.



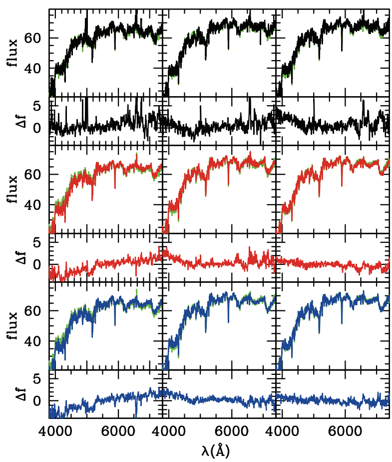
Simulated galaxy distribution in a $150\times150 h^{-2}Mpc^2$ region (h is the Hubble constant divided by $100 km\ s^{-1}Mpc^{-1}$). Each point corresponds to an individual galaxy, whose luminosity of dust emission at a submillimeter wavelength of 0.85mm is calculated individually. Therefore, the figure predicts the early Universe (z = 6) that ALMA would see. The larger a point is, the more luminous the galaxy is. The redder a point is, the larger fraction of energy is radiated in submillimeter. We only plot galaxies that are detectable by ALMA. The gray-scale shows the distribution of the dark matter, whose gravity attracts galaxies. From the figure, we see that ALMA can detect huge number of galaxies. We also find that "red" galaxies are the dominant population. Here, "red" means that a galaxy radiates more in the submillimeter than in the optical (so it is different from normal red). The existence of dust makes galaxies "redder", because dust absorbs optical light and emits submillimeter radiation. We emphasize that if the galaxies have "redder" colors, the importance of ALMA is more pronounced. Therefore, abundance of red points in the figure indicate that ALMA is really essential in observing the early Universe.

Therefore, ALMA (Atacama Large Millimeter/submillimeter Array), which has just started observations in submillimeter and millimeter wavelengths, is expected to detect distant galaxies and large scale structures to a redshift of 6 and beyond, and to reveal the blocked (i.e., "hidden") part of the stellar light and to trace the metal enrichment in galaxies. In the accompanying figure, we show the simulation of large scale structures expected to be seen by ALMA, by Hiroyuki Hirashita, which is presented in Suwa, Hirashita, & Tamura, 2010, Astrophysics and Space Science, 330, 219.

Effects of Feedback from Radio Galaxies

Supermassive black holes (SMBHs) are believed to play an important role in the evolution of galaxies. In particular, the "radio loud" phase during which accretion onto the SMBH results in prodigious outflow of high energy particles is expected to maintain low star formation rates in massive elliptical galaxies. Yen-Ting Lin and collaborators have carried out a comprehensive study of the properties of radio galaxies (RGs) in the nearby Universe. They have proposed a new, objective scheme of classification that allows distinct populations of RGs to be identified, which represents an improvement over the classical Fanaroff-Riley (1974) scheme (see figure below). They suggested that the accretion rates onto the SMBH is the key factor in the formation of three main classes of RGs they identified; from lobe-dominated sources with "hot spots" and optical nuclear emission lines (type A), to lobe-dominated sources without optical nuclear emission lines (type B), to sources with prominent jets close to the nucleus (type C), the accretion rate decreases.

They also suggested that these RGs of different radio morphologies would have different effects on the host galaxies and surrounding environment. The powerful jets from lobe-dominated sources with "hot spots" (type A) could easily penetrate the host galaxy and affect intergalactic/intracluster medium up to scales of hundreds of kpc. On the other hand, the less powerful jets from the other two classes of RGs (type B & C) would have larger cross sections within the host galaxy, and therefore may be quite effective in shutting down star formation activity that may be linked to whatever mechanism that initiated the nuclear SMBH activity. The results of this study have been published in Lin et al., 2010, ApJ, 723, 1119.



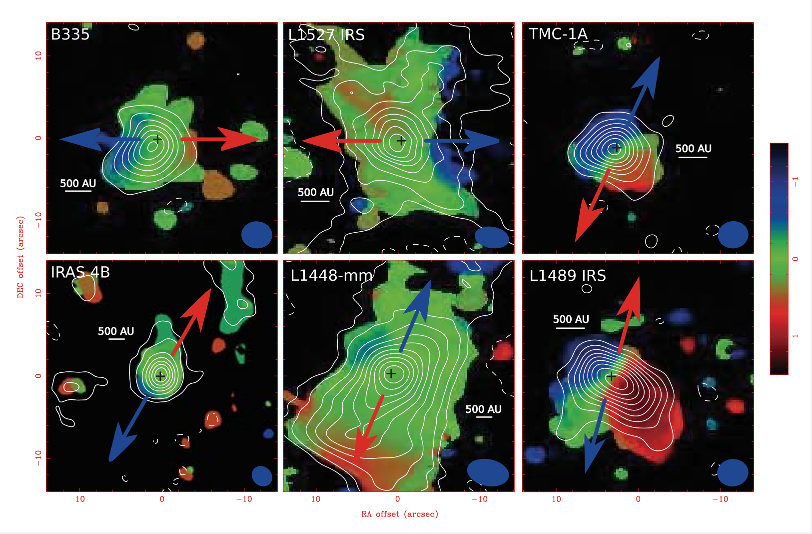
Mean SDSS spectra of RGs of different morphologies and different SMBH masses. From left to right, the columns are of increasing ranges of SMBH mass. Within each column, the top two panels show the mean spectrum of lobe-dominated objects with "hot spots" and optical nuclear mission lines (type A, black curve) and its difference from the radio quiet (RQ) galaxies that have the same SMBH mass and galactic structures (green curve, repeated in other panels in a column). The two panels in the middle are for lobe-dominated RGs without "hot spots" (type B, red curve); the bottom two are for RGs with prominent jets close to the nucleus (type C, blue curve). It is interesting to see in the lower left corner of the figure, for the low mass RGs of type B & C, their mean spectra are redder compared to the RQ counterparts (notice the tilt of the difference spectrum towards shorter wavelengths), and lack of Hα emission line (i.e., the "dip" at 6563Å in the difference spectra), which may be an evidence of feedback from the radio lobes that shutdown the star formation activities.

Star Formation

Envelopes around Protostars

Stars form in interstellar "molecular clouds" of gas and dust. "Protostars" grow through accretion from the surrounding material in the molecular clouds. Because of the surrounding dusty envelopes, protostars are invisible at optical wavelength. On the other hand, at far-infrared, submillimeter, and millimeter wavelengths we can penetrate the dust and study the structures and kinematics of the molecular envelopes, and how stars are formed.

Through observations of molecular lines at millimeter and submillimeter wavelengths we can measure gas motions in envelopes, such as rotations and infall. Our SMA observations in the $C^{18}O$(2-1) line toward a sample of Class 0 and I protostars have revealed systematic gas motions in the envelopes surrounding those protostars, which can be interpreted as envelope rotations (see figure below). Furthermore, we found that the envelopes around the more evolved protostars (Class I) tend to exhibit faster rotations than those around the less evolved protostars (Class 0). These results suggest that the rotational motion in the envelopes around the protostars likely increases with time evolution (Yen, Takakuwa & Ohashi, 2010, ApJ, 710, 1786; 2011, ApJ, 742, 57).

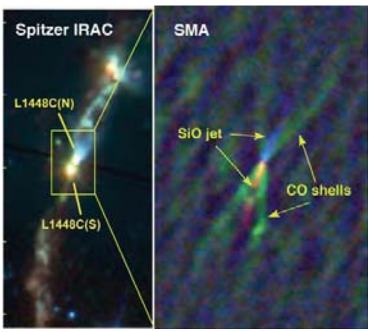


Morphology (contour) and kinematics (color scale) of envelopes around a sample of Class 0 and I protostars seen in the $C^{18}O$(2-1) emission observed with the SMA. The color scale shows gas motions moving away from us (redshifted) and toward us (blueshifted). Dashed lines denote the rotational axes of these envelopes, and black crosses represent the positions of the protostars.

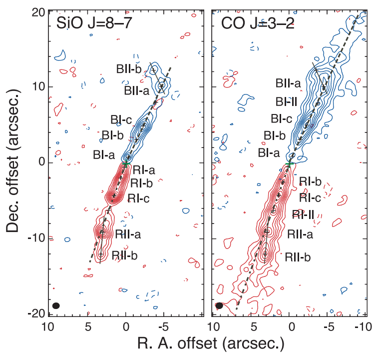
Jets and Outflows Driven by Protostars

A number of protostars are associated with beautiful collimated jets and energetic bipolar outflows. Understanding their driving mechanism and their physical link with protostellar evolution are long-standing issues of star formation. Mass accretion onto the star cannot proceed without removing excess angular momentum from the accreting materials. Theories predict that the magnetized outflowing gas from the protostar plays an important role in this process, but the details are not clear.

The protostellar jet driven by L1448C was observed in the SiO(8–7) and CO(3–2) lines at ~1" resolution with the SMA (see figures below). A narrow jet from the northern source L1448C(N) was observed in the SiO and the high-velocity CO emission. The jet consists of a chain of emission knots with an inter-knot spacing of ~2" (500AU) and a semi-periodic velocity variation. These knots are likely to be the internal bow shocks in the jet beam that were formed due to the periodic variation of the ejection velocity with a period of ~15–20yr. It is found that the jet is extremely active with a mechanical luminosity of ~7$L_\odot$, which is comparable to the luminosity of the central source (~ 7.5$L_\odot$). The mass accretion rate onto the protostar derived from the mass-loss rate is ~$10^{-5} M_\odot yr^{-1}$. Such a high mass accretion rate suggests that the mass and the age of the central star are 0.03–0.09$M_\odot$ and (4–12)×10^3yr, respectively, implying that the central star is in the very early stage of protostellar evolution. The low-velocity CO emission delineates two V-shaped shells with a common apex at L1448C(N). The kinematics of these shells are reproduced by the model of a wide opening angle wind. The co-existence of the highly-collimated jets and the wide-opening angle shells can be explained by the "unified X-wind model" in which highly-collimated jet components correspond to the on-axis density enhancement of the wide-opening angle wind (Hirano et al. 2010, ApJ, 717, 58).

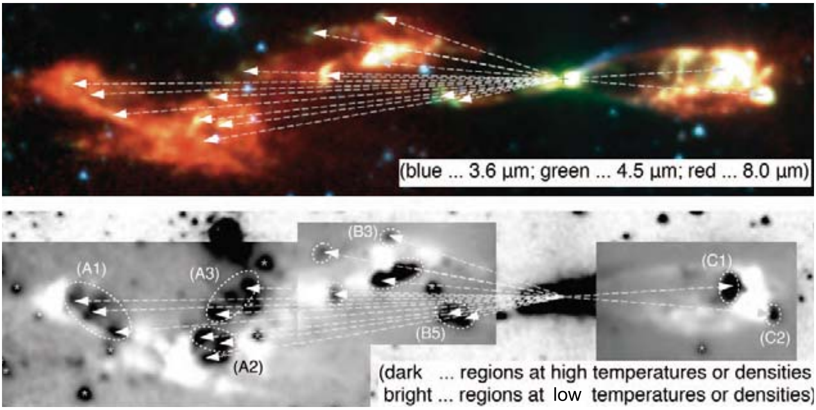


Left: Spitzer IRAC image of the L1448C outflow. Right: Close-up views of the central region of the outflow. CO outflow shells and SiO jet observed with the SMA.



Distributions of the high velocity SiO (left) and CO (right) emission. The velocity ranges are ±51–70kms^{-1} with respect to the systemic velocity. Green cross in each panel denotes the position of the continuum peak of L1448C(N).

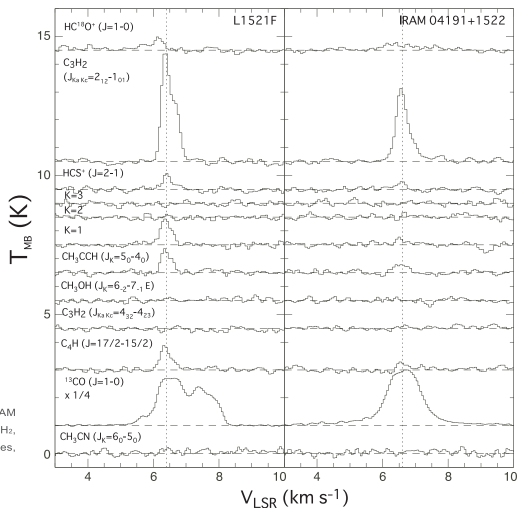
The infrared Array Camera (IRAC) on the Spitzer Space Telescope has provided a huge amount of data that are exceptionally useful for studying star formation in many aspects, including their driving jets and outflows. These show emission from molecular hydrogen, which is the most abundant molecule in space, heated by shock waves in many protostellar outflows. We are exploring a new method to discriminate relatively warm/dense molecular gas from the others (Takami et al. 2011, ApJ, 743, 193, see next figure). This allows us to investigate how the gas is ejected from the star or accretion disk and how the ejected material interacts with the surrounding cold molecular gas.



Top : Distribution of molecular hydrogen emission in the L1157 jet. Blue, green, and red colors show emissions at 3.6, 4.5, and 8.0µm observed with the Spitzer Space Telescope. The infrared emission originates from shock waves in the jet, the speed of which is ~10-30km s^{-1}. Color variation in the figure results from different temperatures or densities of gas. Bottom: Our new analysis for identifying regions at high temperatures and densities (dark) and low temperatures or densities (bright). We speculate that the protostar may act as a "shot-gun", ejecting the gas bullets (dark spots in the figure) with the trajectory shown with arrows, and entraining the surrounding gas seen as bright regions. The features with asterisks are due to stars (i.e., not gas in the jet).

Chemistry in Star-Forming Regions

There are more than one hundred molecular species detected in molecular clouds. It is well known that the chemistry in star-forming regions is non-equilibrium and time-dependent. Molecular abundances in star-forming regions could be used as a clock for the physical evolution of the star-formation process.

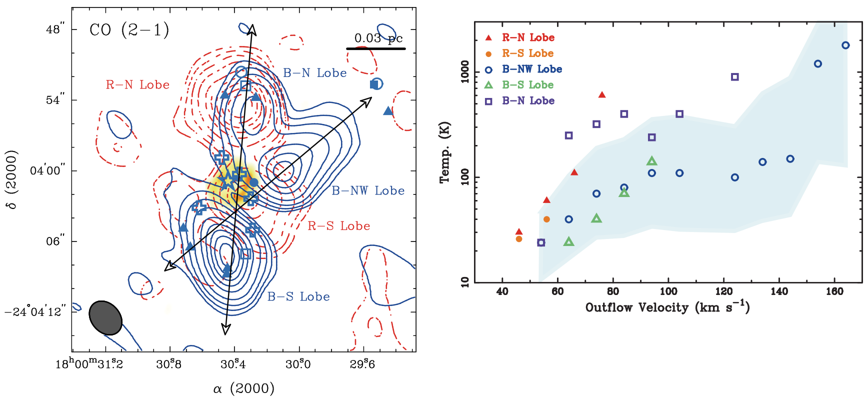


Molecular-line spectra toward L1521F (left) and IRAM 04191+1522 (right). Spectra from molecules such as C_3H_2, CH_3CCH, and C_4H, so-called "carbon-chain" molecules, are more intense in L1521F than in IRAM 04191+1522.

Observations of two archetypal protostellar sources of L1521F and IRAM 04191+1522 were performed with the Nobeyama 45-meter telescope in several molecular lines. These include "carbon-chain" molecular lines, which are tracers of molecular clouds at the early (<10^5 year) chemical evolutionary stage. We found that the carbon-chain molecules are several times more abundant toward L1521F than IRAM 04191+1522 (see figure to the left bottom). This result suggests that L1521F is in the earlier evolutionary stage than IRAM 04191+1522, and that through observations of the chemical status we can trace the evolutionary sequence of protostars (Takakuwa, Ohashi, & Aikawa 2011, ApJ, 728, 101).

Formation of high mass stars

Although molecular outflows have been commonly identified around both low- and high-mass young stellar objects, it is not clear how the bulk of the outflowing gas is accelerated. Exploring the physical conditions of the extremely high-velocity outflowing gas in details will be helpful for clarifying its role in star formation processes. The massive star forming region G5.89-0.39 is associated with energetic CO outflows with velocities up to ~70km s^{-1} from its systemic velocity. With the SMA observations in CO(2-1) and (3-2), we have for the first time estimated the temperature of the outflowing gas as a function of the velocity (see figures below). Our results reveal a clear increasing trend of the temperature with the gas velocity. The observational features of the extremely high-velocity gas associated with G5.89-0.39 qualitatively favor the jet-driven bow shock model.



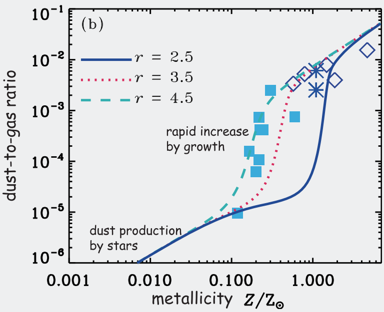
Left : Extremely high-velocity molecular outflows of G5.89-0.39 in CO(2-1) imaged with the SMA. Right: The outflowing gas temperature versus the gas velocity deduced from the LVG calculations. An increasing trend of the gas temperature with the outflow velocity can be discerned toward all lobes (Su et al., 2011, ApJ, 744, L26).

Dust Astrophysics

The evolution of dust content in galaxies

Dust grains are one of the important components of the interstellar medium, as they are responsible for about one third of a galaxy's energy output, even though dust grains only make up about 1% of the interstellar medium mass of a galaxy. Dust grains are small solid particles composed of heavy elements such as C, O, Si, Mg, Fe, and so on (we call these elements metals), and they not only absorb and scatter the interstellar light, but also become ingredients of planets if they are incorporated into protoplanetary disks.

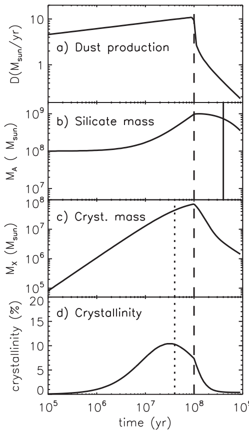
Dust production is believed to take place in the circumstellar environments of dying stars, and subsequently deposited into the interstellar medium. However, it seems that in certain cases, for instance in early galaxies, dust production by evolved stars alone is not efficient enough, and grain growth in the interstellar medium needs to be considered as a significant source of dust. Hiroyuki Hirashita and Tzu-Ming Kuo calculated the evolution of dust content in galaxies by taking into account these two dust production processes, as well as dust destruction by supernova shocks. Because dust grains are composed of metals, the relation between metallicity (fraction of metals in gas) and dust-to-gas ratio is useful to examine the evolution of dust content in a galaxy. The metallicity of a galaxy increases over time, due to the built-up of nucleosynthetic products from stellar ejecta into the interstellar medium and is an indicator of the evolutionary stage of a galaxy.



The figure demonstrates how the dust-to-gas ratio in a galaxy evolves with increasing metallicity. In the low-metallicity regime, the dust is predominantly supplied by stars, so the dust-to-gas ratio increases in proportion to metallicity. Above a certain metallicity, the dust-to-gas ratio rapidly increases because the dust growth in the interstellar medium becomes more and more important, because interstellar dust growth occurs efficiently in metal-rich interstellar environments. The rapid increase is indeed consistent with the observational data of nearby galaxies.

Hirashita and Kuo find that the dust growth is also sensitive to the grain size distribution. The figure includes the results for three different grain size distributions, with a larger r indicating a larger number of small grains. If the abundance of small grains is large, the surface-to-volume ratio of the grains is large; therefore, the grain growth becomes dominant earlier, i.e. at a lower metallicity. The full research report on this topic is presented in Hirashita & Kuo, 2011, MNRAS 416, 1340.

Most of the dust in the interstellar medium in our own Milky Way consists of silicates in a glassy, or amorphous appearance. This is also shown to be the case in most external galaxies, and it is thought that processes such as cosmic ray hits, and interstellar grain growth, cause essentially the entire silicate reservoir to be amorphous. However, a few years back it was shown that some galaxies undergoing a burst of star formation, the so-called starburst galaxies, actually show a considerable fraction of their interstellar silicate mass in crystalline form. Crystallization of silicates occurs in relatively high temperature environments (1,000-1,500^{0}K) usually only found in the dust producing environments of evolved stars, and indeed, a small but measurable fraction of crystalline silicates is often seen around evolved stars. It was argued that in starburst galaxies so much dust production was taking place by massive stars with relatively short life spans, that the crystalline signal from this dust was drowning out the amorphous signal from the interstellar medium.



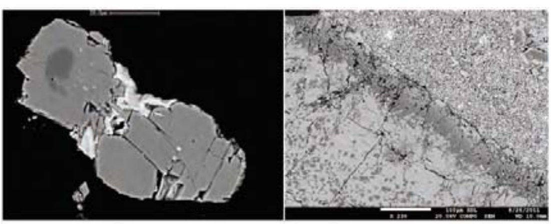
Ciska Kemper and her collaborators put this theory to the test and constructed a model, which includes the dust production, destruction, amorphitization and crystallization rates for a starburst galaxy, depending on the rate of star formation.

The figure shows the result of these calculations: The top panel indicates the total dust production in a starburst galaxy in terms of time after the start of the starburst; the star formation rate is constant and the starburst lasts 100 million years (indicated by the dashed line). The amorphization time scale is indicated by the dotted line, and the destruction time scale by the dash-dotted line. The resulting total silicate mass is shown in panel (b) and the crystalline silicate mass is shown in panel (c). Dividing these two quantities yields the crystalline fraction, or crystallinity, plotted in panel (d), and it is apparent that under certain circumstances a high crystalline fraction may indeed occur in the interstellar medium of starburst galaxies (Kemper et al., 2011, MNRAS, 413, 1192).

Dust astrophysics in the laboratory: Research on refractory solids from primitive meteorites

An end point of the evolution of interstellar dust is the incorporation into solid bodies, such as asteroids, in planetary systems such as our own Solar System. Meteorites are fragments of asteroid bodies that fall to the Earth's surface. A class of meteorites is called "primitive meteorites", whose bulk chemical compositions are essentially identical to that of the solar photosphere. These primitive meteorites contain various components that formed at high temperatures in the very beginning, or even before the birth, of the Solar System. Refractory inclusions, such as Ca-Al-rich Inclusions (CAIs), hibonite ($CaAl_{12}O_{19}$) and corundum (Al_2O_3) grains, are some of the meteoritic components of Solar System origin, and carry important constraints on the timing and astrophysical environment of the Solar System formation.

Another type of meteoritic constituents is the presolar dust grains. They are tiny solid condensates (1 micron in size or less) from the stellar winds of evolved stars that ended their lives before the Sun formed. Presolar dust grains survived the interstellar passage and destructive processes in the early Solar System and were finally incorporated into asteroid parent bodies. As presolar grains were part of their parent stars, they formed with the products of stellar nucleosynthesis, and thus can be recognized by their unusual isotopic compositions. Combined with theoretical modeling, these grains could serve as a direct probe to understand the nuclear processes inside stars. At ASIAA, Typhoon Lee and Ming-Chang Liu, and their team study both Solar System and presolar solids for their chemical and isotopic compositions. They aim at better understanding the chemical and physical processes that occurred when the Solar System formed, and its subsequent evolution, and to improve our knowledge about stellar nucleosynthesis.

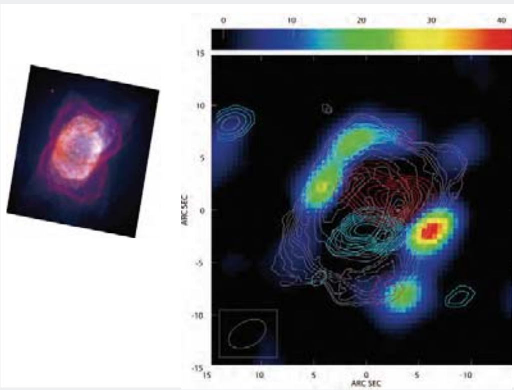


The left figure shows a meteoritic hibonite grain extracted from the Murchison meteorite. The dark inclusion on the upper left is corundum. The bright part in the middle is material from the matrix. The right figure shows a corner of a Ca-Al-rich Inclusion from the Allende meteorite. A well-formed rim (the dark band from the upper left to the lower right), Wark-Lovering Rim, can be clearly seen in the picture. Its exact origin is still under debate, but one generally accepted model is that they formed by flash heating that occurred in the solar nebula. (Picture Credit: Cheng-Kai Wang)

Evolved Stars

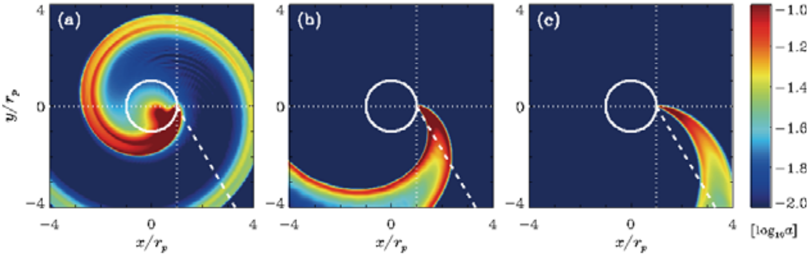
Cool red giants and red super-giants lose mass through a slow and dusty wind. As a result, the stars are enshrouded by a massive expanding envelope of dust and molecular gas. In this phase, stars emit a lot of energy and consequently, the circumstellar envelopes are bright sources and rich in atomic and molecular emission lines. They constitute ideal targets to study many different physical and chemical processes, which are taking place simultaneously inside the envelope, and also to understand their stellar evolution.

Just before dying, Sun-like stars become very large, expanding to about 250 times the size of our Sun, which means that the surface of these stars would extend out to the Earth's orbit. A dying star expels most of its material in the form of molecular gas, and only the central core, which is very hot ($100{,}000^{0}$K), but very small, will remain. The hot central core emits ultraviolet radiation that destroys and ionizes the previously ejected molecules, thus forming a so-called Planetary Nebula. The figure below shows young Planetary Nebula NGC 7027, for which the gas ejection has just stopped, and the destruction of the molecules and ionization of the gas has just started. With the SMA, we imaged the destruction process: molecules are destroyed into the formyl ion (HCO^+) before being completely destroyed into H, C and O. Eventually these atoms will ionize, and become H^+, C^+ and O^+, in a few thousand years (Huang et al. 2010, ApJ, 722, 273).



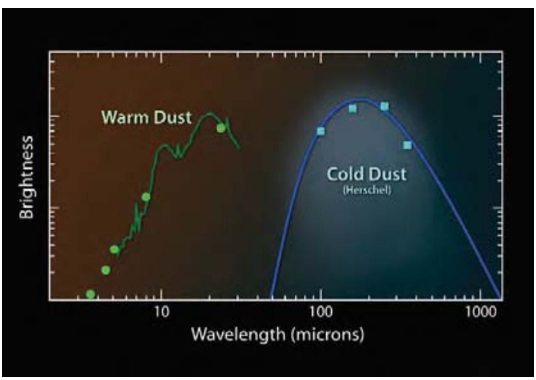
Left: Color composite of the Hubble Space Telescope optical and infrared images of NGC 7027. Molecular hydrogen emission (H_2) is shown in pink, and the Hα line, associated with ionization is shown in white. Courtesy Space Telescope Science Institute. Right: False color-scale image of the HCO^+(3-2) emission (at the systemic velocity) that is moving sideways (in the plane of the sky). Red and blue contours indicate HCO^+(3-2) emission from gas moving away from us and towards us, respectively. The horizontal structures correspond to the equatorial ring of H_2 emission seen in the image on the left. The white contours represent the same H_2 image as the pink-scale on the left.

The mass-loss that a Sun-like star undergoes at the end of its life manifests itself as a very dense stellar wind, which will interact with any brown dwarfs or planets that are orbiting the star. The gravitational interaction of the substellar mass objects with the strong stellar wind can potentially create a spiral density wave in the gaseous stellar outflow, with the exact tightness and the shape of the spiral depending on the wind speed and orbital properties. The figure below shows a comparison of the shape of the spiral pattern between models with wind Mach numbers of 0, 5, and 10 respectively, where the Mach number represents the number of times the wind speed exceeds the local sound velocity (Kim & Taam, 2012, ApJ, 744, 136).



Spiral density patterns calculated for the interaction between a dense stellar wind and a planet or brown dwarf orbiting the mass-losing star. The three panels show the results for three different wind speeds: corresponding to Mach numbers of 0, 5 and 10, here the Mach number is the number of times the local sound speed is exceeded. The circle indicates the orbit of the planet or brown dwarf, with its current location at the intersection of the dotted lines. The dashed lines denotes the opening angle of the spiral in a static medium, from which the corresponding models with faster winds start their spiral pattern. The resulting density enhancement is indicated by the color scale.

Massive stars, with initial masses more than 8 times the mass of the Sun, do not end their lives with a phase of gradual mass loss, but in a rather more explosive way. Although they are more massive than the Sun, these stars are more luminous and burn through their huge fuel reservoir in a very short time, a hundred to a thousand times faster than our Sun. When the fuel is exhausted, the star becomes unstable, and explodes in a spectacular way. In 1987, such a supernova occurred in the Large Magellanic Cloud, which is a satellite galaxy to our own Milky Way. This was the nearest recorded supernova since almost four centuries, and provides an excellent opportunity to study the physics of stellar explosions. Today, the supernova remnant is still clearly visible, and evolving. More than 20 years after the explosion, observations with the Herschel space telescope revealed that SN 1987A, as it is known, has produced a huge amount of tiny dust particles, adding up to about 200,000 times the mass of the Earth (Matsuura et al. 2011, Science, 333, 1258). The figure below shows the spectral energy distribution of the dust emission. Masaaki Otsuka was part of the discovery team. The discovery helps to understand the origin of dust in the early universe. Dusty galaxies are found at a time that the universe is less than 1 billion years old. The short life time of massive stars and the huge dust production in supernovae can explain the presence of large amounts of dust at such early times in the history of our universe.

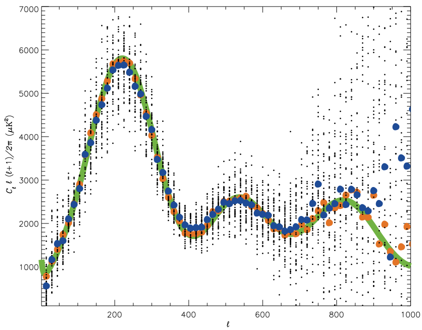


The infrared emission from supernova 1987A in the form of a spectral energy distribution. The green points and line show observations obtained with the Spitzer Space Telescope, tracing the amount and composition of the warm dust in the supernova remnant. Although a clear signal is seen, only a relatively small amount of dust is needed to explain the emission. The blue data points show the detections obtained with the Herschel Space Telescope in the far-infrared. To emit at these wavelengths, the dust must be cold, and it also requires a large quantity of dust. The blue line indicates a model for the thermal dust emission, corresponding to 200,000 Earth masses worth of dust particles.

Cosmology

Cosmic Microwave Background

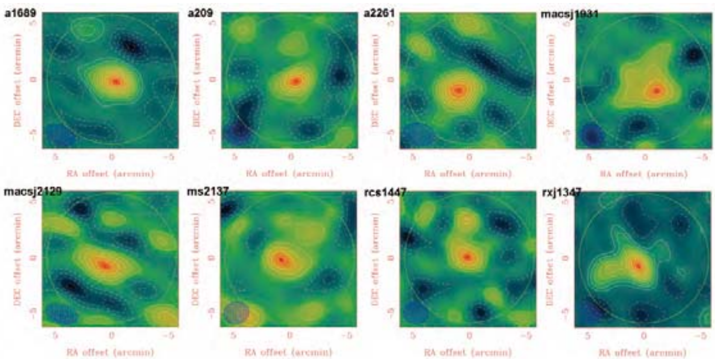
The angular power spectrum of the cosmic microwave background (CMB) temperature anisotropies is one of the most important measurements for defining the fundamental characteristics of the Universe such as its geometry and total density. Lung-Yih Chiang and Fei-Fan Chen (Chiang & Chen, 2011, ApJ, 738, 188; 2012, ApJ, 751, 43) used the flat-sky approximation and Fourier analysis to estimate the angular power spectrum from an ensemble of square patches from the WMAP W and V frequency band maps which have the least amount of foreground contamination.This method circumvents the issue of foreground cleaning and that of breaking orthogonality in spherical harmonic analysis due to masking out the bright Galactic plane region. The patches are chosen with the criterion of minimizing the variance of the temperature anisotropies. A lower variance implies a smaller foreground contamination in the patch. We test and confirm Gaussian statistical characteristics for the selected patches. We reproduce the first and second acoustic peaks of the power spectrum. The third acoustic peak is also clearly visible albeit with some noise residuals at the tail.



Direct measurement of the CMB angular power spectrum. From WMAP V band map we choose patches with σ < 98μK (after eliminating bright point sources), and we take the cross-power spectra of patches between WMAP V and W band. After deconvolution of the window functions, the power spectra of the 47 patches are shown in black dot and the mean power spectrum is in big blue dot. For comparison we plot in big orange dot the power spectrum binned ($\triangle l$ = 15) from that by the WMAP science team. The best-fit ΛCDM model is in the green solid line.

Galaxy Clusters

Galaxy clusters provide an independent means of examining any viable model of cosmic structure formation through the growth of structure and by the form of their equilibrium mass profiles dominated by Dark Matter of an unknown nature. Imaging Galaxy clusters complements CMB and galaxy clustering observations.

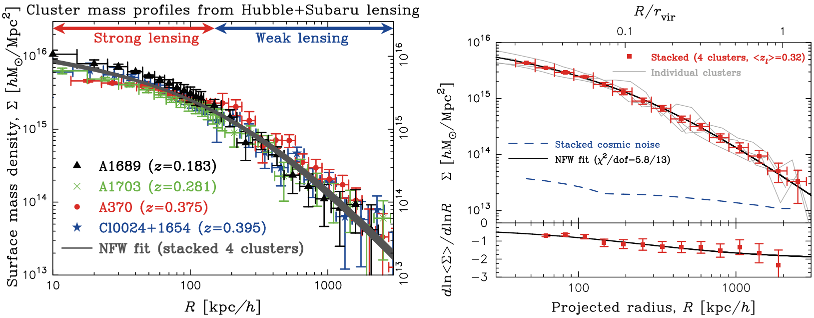


SZE maps of 8 clusters observed by AMiBA 13-element array. Map size is 12'x12', slightly larger than the half-power width of the primary beam. Synthesized beam is presented at lower-left corner of each plot. Contours show the significance of detection starting from +/- 1 sigma, separated by 1 sigma.

Data reduction and finding and improving the systematics of AMiBA have been major efforts of the cosmology group. Since June 2011, science operation of the 13-element array of AMiBA (AMiBA-13) has been routinely carried out. The accompanying figure highlights 8 galaxy clusters measured by AMiBA-13 through the SZE.

Based on measured performance and theoretical cluster model prediction, AMiBA-13 should be able to detect all clusters with virial mass greater than $7\times10^{14}M_{\odot}$ within a typical on-source integration of 50 hours.

Keiichi Umetsu and collaborators explored the full strength of cluster gravitational lensing for obtaining highest-precision cluster mass profiles, by combining all possible lensing information available in the cluster regime, namely weak-lensing distortion, magnification, and strong-lensing measurements (Umetsu et al., 2011a, ApJ, 729, 127; Umetsu et al. 2011b, ApJ, 738, 41). We have formed an averaged full-radial mass profile for four high-mass clusters by stacking strong and weak gravitational lensing measurements from high-quality Hubble Space Telescope and Subaru images. The stacked cluster mass profile has a continuously steepening gradient out to beyond the virial radius, in remarkably good agreement with the standard Navarro-Frenk-White (NFW) form predicted for the family of cold dark matter (CDM) dominated halos in gravitational equilibrium. The central slope is constrained to lie in the range, -dln[rho]/dln[r] =0.89 (+0.27, -0.39), which is fully consistent with the standard NFW prediction, -1. This result is important in the sense that it confirms one of the basic assumptions in cluster cosmology in which the density profile of clusters is assumed to follow the NFW profile.

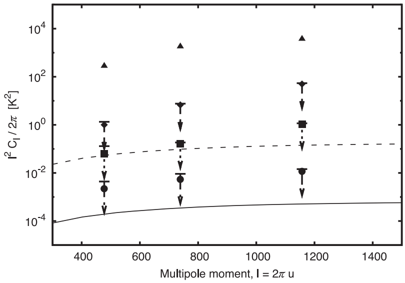


Radial mass profiles measured for four well-studied, strongly-lensing galaxy clusters (Left panel). All have similar mass profiles as measured from Hubble observations of strong-lensing and Subaru observations of weak-lensing distortion and magnification (Umetsu et al. 2011a, their Figure 6; Postman et al. 2012, ApJS, 199, 25, their Figure 1). The averaged mass profile of these four clusters (Umetsu et al. 2011b, their Figure 1), shown in the right panel, is in remarkably good agreement with the standard NFW form predicted for the family of CDM-dominated halos in gravitational equilibrium. The NFW fit is also shown in the left panel by the gray area (2 sigma confidence interval of the NFW fit). Both strong and weak lensing probes are required to map the continuously steepening mass profile from the inner core (R~10kpc/h) out to beyond the virial radius (R~2,000kpc/h).

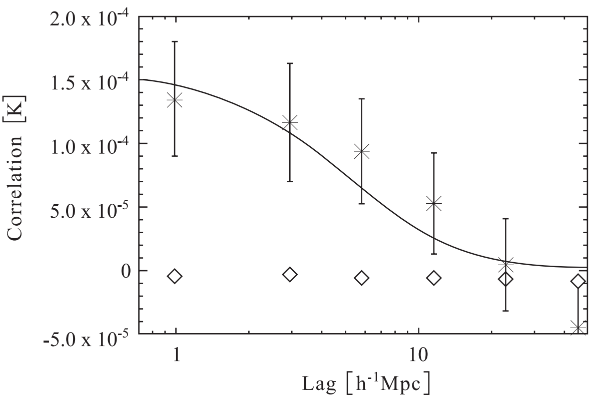
21-Centimeter Cosmology

21-cm Cosmology has recently emerged as an exciting field in cosmology. Neutral hydrogen is the most abundant baryonic matter in the universe, and its hyperfine transition at 21-cm can in principle be observed up to very high redshifts. Currently, there are two observational windows: At redshifts around 10, the 21-cm radiation traces the history of reionization and maps out its process, shedding light on the formation of luminous objects. And, at redshifts around unity, neutral hydrogen follows the distribution of large scale structure, and can be used for precision measurements of the properties of dark energy when it started to dominate the energy content of the universe. Tzu-Ching Chang and collaborators have been working on both aspects of the science. For epoch of reionization (EoR), we have been utilizing the Giant Metrewave Radio Telescope (GMRT) in India to measure the 21-cm power spectrum at redshifts $8 < z < 9$, constraining the fluctuation of ionization. We have put a first upper limit on the amplitude of the power spectrum at a mean redshift of 8.5 (Paciga et al. 2011, MNRAS, 413, 1174), as shown in figure below. The upper limit is within one order-of-magnitude of the currently popular theoretical expectations, and already rules out models where the intergalactic medium was not heated before reionization.

Average power spectrum in units of K^2, as a function of the multipole moment l. Each point is shown with a 2σ upper limit derived from a bootstrap error analysis, which is in most cases smaller than the size of the point. The points are logarithmically spaced from left to right covering the ranges $377 < l < 578$, $578 < l < 899$ and $899 < l < 1414$. Triangles are the power before subtracting foregrounds, diamonds are after 8MHz mean subtraction, squares are after 2MHz mean subtraction and circles are after 0.5MHz subtraction. The curved solid line is the theoretical EoR signal from (Jelić et al. 2008, MNRAS, 389, 1319), and the dashed line is the theoretical EoR signal with a cold absorbing IGM.



At redshifts around unity, we have recently reported a cross-correlation measurement of 21-cm emission measured by the Green Bank Telescope, and the optical galaxies measured by the DEEP2 galaxy survey (see figure below).The redshifts of the cross-correlation is at $0.5 < z < 1.1$, and at the mean redshift of 0.8, we have reported a HI-optical cross-correlation amplitude that yields constraints on the neutral hydrogen mass content at z=0.8 and its bias factor on $10h^{-1}$Mpc comoving scales (h is the Hubble parameter and the value is 0.7). (Chang et al., 2010, Nature, 466, 463). This is the highest redshift detection of neutral hydrogen, and opens up a promising window for using 21-cm as tracers of the matter distribution, and eventually as a powerful tool for measuring the Baryon Acoustic Oscillation (BAO) features, shedding light on properties of dark energy.

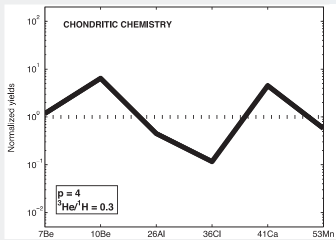


A cross-correlation measurement of 21-cm emission measured by the Green Bank Telescope, and the optical galaxies measured by the DEEP2 galaxy survey.

Planetary Science

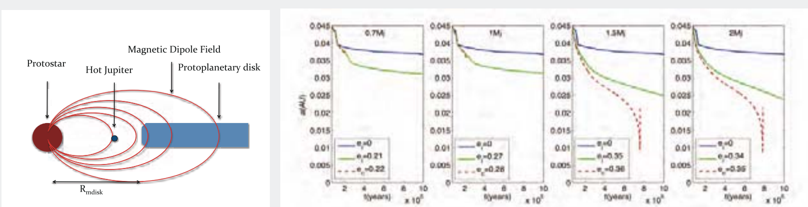
A number of researchers have been working on cosmochemistry of meteorites and building the telescopes called TAOS for detection of the Kuiper Belt Objects. The goal of these projects is to better understand the conditions of the solar nebula and the early evolution of the Solar System. Here we only present one study for the Solar System and refer the interested readers to the “Evolved Stars” and “TAOS” sessions for more details. Besides the Solar System, exoplanetary systems are being studied as well.

By modeling the abundance of radioactive elements found in calcium-aluminum-rich inclusions (CAIs) of meteorites, the origin and the evolution of the solar nebula is gradually being unraveled. Two explanations exist for the short-lived radionuclides (half-life $T_{1/2}$ < 5 Myr) present in the solar system when CAIs first formed. They originated either from the ejecta of a supernova or by the in situ irradiation of nebular dust by energetic particles. With a half-life of only 53 days, ^{7}Be is the key discriminant, since it can only be made by irradiation. With theoretical models of the early solution system, the yield of ^{7}Be can be calculated (see figure to the right). The X-wind model provides a natural astrophysical setting that gives the requisite conditions. The upcoming NanoSIMS, a new generation of secondary ion mass spectrometer with nano-meter spatial resolution, will be used to experimentally determine the initial abundance of various short-lived radionuclides in meteoritic components. By comparing with the model calculations, these results will shed light on the immediate astrophysical environment of the nascent solar system.



Yields of ^{7}Be, ^{10}Be, ^{26}Al, ^{36}Cl, ^{41}Ca, and ^{53}Mn for a chondritic chemistry and the spectral parameters p=4 and ^{3}He/^{1}H=0.3. The yields are normalized to the experimental values, corresponding to the horizontal dotted line. For ^{41}Ca, we have adopted the initial value ^{41}Ca/^{40}Ca =3.9×10^{-7}, more likely than the canonical ratio (Gounelle et al., 2006, ApJ, 640, 1163).

Hot Jupiters are so close to their parent stars that their equilibrium temperatures can soar up to 1,000-2,000^{0}K. There exists an intriguing phenomenon for these “toasted exoplanets”: no hot Jupiters of mass less than 1 Jupiter mass have been found within 0.03AU from their parent stars. A model has been constructed to explore the cause. When the system is in the T Tauri star phase, the strong magnetic dipole fields of the protostar truncate the inner part of the proto-planetary disk at the disk radius R_{cavity}, forming a magnetospheric cavity. A young hot Jupiter is expected to lie in the magnetospheric cavity. If the young planet starts with an eccentric orbit, tidal dissipation can expand the planet. As shown in the figure below, a less massive planet requires a smaller critical eccentricity to be disrupted, meaning that tidal dissipation can inflate a less massive planet more easily, leading to the demise of a less massive hot Jupiter due to the runaway mass loss via Roche-lobe overflow.



The left plot illustrates our model, which shows a hot Jupiter orbiting a CTTS in a magnetospheric cavity of a protoplanetary disk. The initial orbit of the planet is set to lie at the 2:1 orbital resonance with the inner edge of the disk. The right plots show the orbital evolution through tidal and magnetic interactions between a hot Jupiter and its host star in a magnetospheric cavity. Four cases are presented in terms of different initial masses: 0.7, 1, 1.5, and 2 Jupiter masses (Mj). Each panel has three different tracks by modulating the initial eccentricity. The blue line is the orbital evolution of a planet in a circular orbit; the green line illustrates the case in which the planet of a given initial mass can migrate inward over the longest distance; the red line shows that the planet with a critical eccentricity is destroyed at the breaking point (Chang, Gu & Bodenheimer, 2010, ApJ, 708, 1693).

Instrumentation Research

Instrumentation Research

ASIAA has always focused on developing forefront technology programs which will drive the next generation of instruments. In our first decade, ASIAA concentrated on establishing a strong research program in radio astronomy. The assembly of a strong team which can develop its expertise in millimeter and submillimeter wavelength technologies has been the driver for the Submillimeter Array (SMA), the Array for Microwave Background Anisotropy (AMiBA), and the ALMA programs. The technical group now has a broad range of capabilities, including superconductor-insulator-superconductor mixers and Superconducting Quantum Interference Device (SQUID) chips, Monolithic Microwave Integrated Circuit (MMIC) devices, IF electronics, cryogenics, correlator, submillimeter wavelength antennas, carbon fiber reflectors, and control software. In our second decade, ASIAA began to develop a technical group in optical/infrared (OIR) wavelengths. This assembled team has been the driver for the TAOS and CFHT/WIRCam programs. The success of the WIRCam collaboration brought the experience of array testing and control electronics to be part of the core expertise of the OIR laboratory. With such expertise, we continue to work on advanced instrumentation projects on large telescopes, such as Spectropolarimètre Infra-Rouge (SPIROU) of CFHT and Hyper SuprimeCam (HSC) and Prime Focus Spectrograph (PFS) of Subaru telescope. Negotiation with Japanese space agency JAXA to join the next generation infrared satellite project, the Space Infrared telescope for Cosmology and Astrophysics (SPICA), is ongoing. In addition, working on the future thirty-meter class telescope instruments is also planned.

The research on instrumentation in ASIAA includes receiver technology development, microwave device design and assembly, superconducting device development, digital technology, and OIR detector array development. ASIAA will continue to expand on its technical development groups, with the goal of increasing capabilities in detection sensitivity in various domains.

Receiver Laboratory

Microwave Device Laboratory

Superconducting Device Laboratory

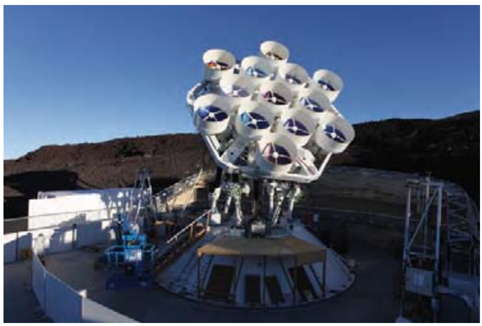
Optical/Infrared Laboratory

Receiver Laboratory

Developing forefront technology to drive the next generation of astronomical instrumentation is one of the core programs in ASIAA. The SMA was our first major instrumentation achievement, and through its construction we have assembled a strong technical team in millimeter and submillimeter wavelength technologies. The SMA has become the workhorse for the ASIAA science program before the ALMA comes online. In parallel, our technical program has expanded further into new projects, such as the AMiBA telescope, the various sub-programs for the ALMA, the digital correlator upgrade for the SMA, and the VLBI in submillimeter wavelengths.

The Submillimeter Array, an eight-element radio telescope ensemble is currently one of the most powerful telescopes directly accessible by the astronomers in Taiwan. With its observing frequency of 180-690GHz, the SMA is an unique instrument in the world. (Picture Credit: Jonathan Weintroub)

Our capability of system design and integration has been demonstrated in the AMiBA project. The AMiBA is an international endeavor led by ASIAA, in collaboration with various laboratories and experts in the world. The receiver lab took on the technical driving role in this project. In November 2002, after two years of development, the ASIAA receiver team has successfully established the AMiBA prototype receiver system on the site of Mauna Loa Observatory, on the big island of Hawaii. In 2005, the telescope site infrastructure was completed, and the telescope mount was erected on Mauna Loa. The AMiBA 7-element was officially dedicated in Oct. 2006, and the 13-element, 1.2 meter full array was completed in 2010.



The 13-element, 1.2meter-dish Yuan T. Lee AMiBA at the Mauna Loa Observatory, Hawaii. The AMiBA project, observing at 3mm wavelength, is an important initiative to develop our observational cosmology program in a very competitive field of science. This project has challenged several novel technological difficulties, such as the 16GHz, wide-band analog correlator, an unprecedented size of Steward mount, and a 6-meter, detachable, composite-material platform. (Picture Credit: Chih-Chiang Han)

The AMiBA project has brought one additional important technology into the receiver lab, which is the design capability for MMIC. We have applied this technology to the AMiBA project in the area of front-end amplifiers, mm-wave mixers, and broad-band correlators.

The ASIAA receiver group is constantly seeking opportunities to undertake challenging projects. Its role in ASIAA is to stay ahead in developing technologies to enable new research directions, and to support new initiatives into unexplored regimes of our discipline.

Left top : One of our new initiatives is to find a new site for submillimeter telescope. Such effort needs a long-term monitoring of the sky transparency in radio wavelength. In August 2011, ASIAA personnel, Pierre Martin-Cocher (shown in photo) and Keiichi Asada deployed the 225GHz radiometer to the Summit Camp of Greenland. (Picture Credit: Keiichi Asada); Left botom : Retrofitting one of the ALMA prototype antennas for the use of VLBI in submillimeter wavelength. This picture shows the preliminary inspection of the antenna in July 2011, at the site of the Very Large Array near Socorro, New Mexico. This effort is led by ASIAA personnel, Philippe Raffin, Ted Huang, and Pierre Martin-Cocher, in collaboration with the engineers from Aeronautical Research Laboratory. (Picture Credit: Nimesh Patel)

This photo demonstrates the ASIAA capability in photoelectrical integration capability. Led by Derek Kubo and Ranjani Srinivasan (ASIAA Hawaii), we have successfully fabricated and delivered two testing equipments for the ALMA project. Both the equipments are based on the laser to radio-frequency synthesizer using the Mach Zehnder modulation technique, and they both show exceptional phase stability in radio frequency. (Picture Credit: Derek Kubo)

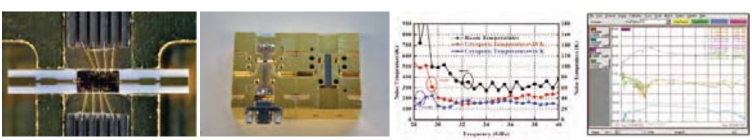
Microwave Device Laboratory

The microwave device laboratory is dedicated to the research and development of the microwave and millimeter-wave electronic devices and circuits for the key components of the radio astronomical instrumentations. The present development items in the microwave device laboratory are (1) cryogenically cooled millimeter-wave broadband low-noise amplifiers for heterodyne receiver front-end, (2) broadband diode and transistor mixers for next-generation astronomical heterodyne receivers, (3) ultra-low-phase-noise broadband tuning voltage-controlled transistor oscillators for local oscillators of next generation astronomical heterodyne receivers. Instrumentation projects supported by the laboratory include the lowest frequency bands of Atacama Large Millimeter/submillimeter Array (ALMA).

Cryogenically cooled millimeter-wave broadband low-noise amplifiers

For frequencies below 100GHz, cryogenically cooled millimeter-wave broadband low-noise amplifiers based on InP based high-electron-mobility transistor (HEMT), metamorphic HEMT, or SiGe hetero-junction bipolar transistor (HBT) provide low noise performance approaching to quantum limit with positive gain. Thus, they are suitable to be used in heterodyne receiver front-end for astronomical instrumentation. The amplifiers currently developed are mainly for the 30-50GHz frequency range to cover Band-1 receiver for ALMA. The figures below show the monolithic microwave integrated circuit chip of the 30-50GHz low-noise amplifiers in the housing and the cryogenic noise performance.

(a) (b) (c) (d)

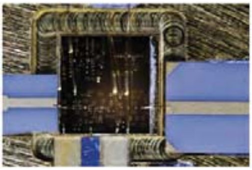


Monolithic microwave integrated circuit of the 30-50GHz cryogenic low-noise MHEMT amplifiers, (a) detail view of the packaged module,(b) split blocks of the packaged amplifier module, (c) measured cryogenic noise performance (d) measured cryogenic scattering parameters. This is a collaborative project between ASIAA and National Central University.(Picture Credit: W.T.Wong and C.C. Chiong)

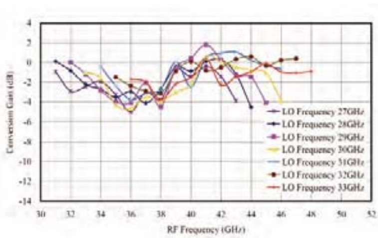
Broadband diode and transistor mixers

Diode or transistor mixers are the frequency conversion devices for amplifier-front-end receivers. Before the laboratory was formally established, a series of 85-105GHz W-band subharmonically pumped diode mixers were developed for the AMiBA project. The most recently developed item is a cascode transistor mixer with positive conversion gain for 30-50GHz, which will be incorporated in the Band-1 receiver for ALMA. Figures below show the mixer and its measured conversion gain.

(a)



(b)



Monolithic microwave integrated circuit chip of the 30-50GHz GaAs PHEMT cascode mixer, (a) packaged module, (b) measured conversion gain. This is a collaborative project between ASIAA and National Taiwan University.(Picture Credit: Y.J. Hwang and C.C. Chuang)

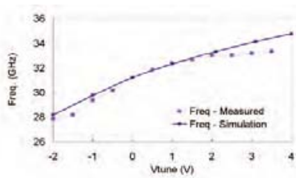
Ultra-low-phase-noise broadband tuning voltage-controlled transistor oscillators

This item is aimed at developing a new generation of compact and low-thermal-dissipation, all-electronic-tuning millimeter-wave signal source for high quality local oscillator for astronomical heterodyne receivers. The development includes two parts, one is the GaAs HBT varactor-tuned voltage-control-oscillator MMIC, the other part is the phase-lock circuit and the integration and optimization of the phase noise performance of the oscillator. The most recent iteration shows that the measured RMS phase jitter of the optimized phase-locked GaAs HBT varactor-tuned voltage-control-oscillator can be as low as 54fs (fs = fanto-second = 10^{-15} sec) at 33.5GHz. This measured result is slightly better than the measured RMS phase jitter of the optimized phase-locked YIG oscillator, which is used as the current local oscillator module for ALMA receivers.

(a)

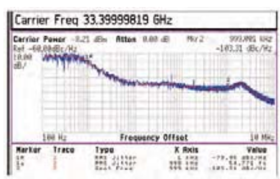
(b)

(c)



(d)

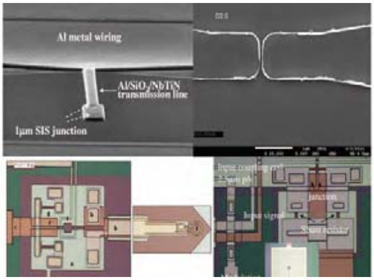
(e)



Ultra-low-phase-noise broadband tuning voltage-controlled transistor oscillators (a) a GaAs HBT voltage-control-oscillator MMIC chip fabricated in a local semiconductor foundry, (b) the packaged circuit module, (c) the measured frequency tuning range, (d) the phase-lock circuit module, and (e) measured phase noise plot of the VCO integrated and optimized with the phase-lock circuit. The goal of this development project is to provide possible miniaturized low-thermal dissipation local oscillator source for the Atacama Large Millimeter/submillimeter Array. This is a collaborative project between ASIAA, National Taiwan University, and the National Radio Astronomical Observatory (USA). (Picture Credit: C.C. Chiong and Y.F. Kuo)

Superconducting Device Laboratory

The Superconducting Device Developing Group is led by Dr. Ming-Jye Wang. This group was formed in 1994 with collaboration with Prof. Cheng-Chung Chi and Prof. Maw-Kuen Wu at National Tsing-Hua University (NTHU), Hsin-Chu, Taiwan. The main goal of this research group is providing sensitive superconducting devices for ASIAA's astronomical projects and also for worldwide collaborators. Currently, the group members include three faculties, one postdoc, five engineers, and two students.



Fabricated devices including mixer, 60nm wide gap, two SQUID chips for scanning SQUID systems.

Clean room for Nb-based superconducting device fabrication at Tsing-Hua campus, Hsin-Chu, Taiwan (about 100km from Taipei).

Laboratories in ASMAB building (NTU campus in Taipei) including clean room, post process (lapping and dicing), and testing systems.

Our fabricating process was established completely in 2000. Currently we have two clean rooms at NTHU and NTU campus respectively. Our laboratory includes a complete fabricating line for Nb-based superconducting devices. The facilities include metal sputtering system, mask aligner, insulator deposition system, resistor evaporator, RIE system, ICP-RIE system, ion milling system, substrate lapping machine, chip dicing system, and wire bounding machine. The minimum pattern is 1μm. Critical current density of SIS junction is from 300A/cm^2 to 20A/cm^2. Multilayer process is also available. Substrate of 30μm thickness is achieved and the width accuracy of chip is better than 5μm. We have the capability of fabricating high quality Nb-based superconducting devices.

Mixers for 200, 300, 380, and 600GHz for the Sub-millimeter Array (SMA) project of ASIAA have been delivered. These devices are working in the receiver systems of the submillimeter telescopes on the summit of Mauna Kea, Hawaii. In addition, two types of SQUID have been fabricated and installed in different Scanning SQUID system in Prof. Chi's laboratory for studying the magnetic properties of material at low temperature.

Currently, we are working on the following topics: (1) Wide IF bandwidth SIS mixers, collaborating with the Smithsonian Astronomical Observatory (SAO) for future SMA detectors; (2) Focal plane multi-pixel heterodyne receiver system with integrated dual polarization mixer; (3) The mixers working at ALMA band-10 frequency range; (4) Hot electron bolometer (HEB) by using NbTiN, NbN, or other novel materials. To achieve the fabrication of these devices, we are developing the fabricating capabilities on NbTiN, NbN, membrane process on Si wafer, nano patterning by using E-beam writing system.

High quality NbTiN films with superconducting transition temperature ~16^{0}K and residual resistivity below 100μm-cm have been achieved. The film quality is good for mixers working at the THz frequency regime. For HEB devices, an ultra thin film is needed. We also plan to deposit epitaxial NbN film at high temperature (~800^{O}C) which can be used in HEB and all-NbN SIS junction. Dry etching process of Si by using RIE system for membrane structure has been tested. Such a process is planned for integrated dual polarization mixer fabrication combining with back-side alignment tool. Nano-patterning technique is introduced by using E-beam lithography incorporated with SEM (model JSM-7001F). This technology can be widely used in the fabrication process of future devices, such as deep sub-mm size SIS junction, HEB, TES, and SSPD.

Optical/Infrared Laboratory

Through various projects, the optical/infrared (OIR) lab has developed array testing facilities and control electronics as the core expertise of the OIR laboratory. With such expertise, we continue to work on advanced high speed cameras for various projects including the near IR guiding camera for CFHT/SPIROU project, metrology camera for Subaru/PFS project and wide field camera for the Trans-Neptunian Automated Occultation Survey (TAOS II) project. The OIR group also focuses on the detector technology, especially on the scientific CMOS sensor and infrared array development.

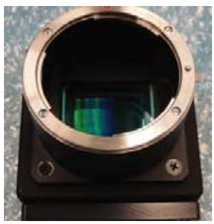
CMOS sensor development

The low noise and high quantum efficiency performance of CCDs are essential for astronomical applications. The major drawback of CCDs is the relatively slow readout speed which limited the frame rate and minimal exposure time. IAA faces the needs for high sampling imaging in our TAOS II and Subaru/PFS projects. In such applications, CMOS sensor has shown more potential than the CCDs.

There has been some fundamental development on the scientific CMOS sensors. The quantum efficiency of over 80% at 500nm with low readout noise has been demonstrated. For TAOS II, we are working with e2v to design a large format device. The device will have 4.5k by 1.9k pixels. With the capability of selected read, we can sample the target stars at 20Hz with readout noise lower than 5e-.

For PFS metrology camera, we collaborate with Canon for the CMOS development. The metrology camera requires large number but small pixels to provide enough spatial resolution for the accurate centroid calculation. We have tested a 10M pixel CMOS camera from Canon. The camera shows low readout noise at room temperature and high pixel rate. The performance is satisfactory. Canon is now developing an even larger format camera for PFS project. We expect to test the sensor soon.

In addition, we have contacted Taiwanese CMOS sensor companies for the scientific sensor array development. A small 256×256 prototype device is now under development targeted for low noise and high dynamic range performance. We will help on the testing of the device. This can help the local company to develop a niche market.



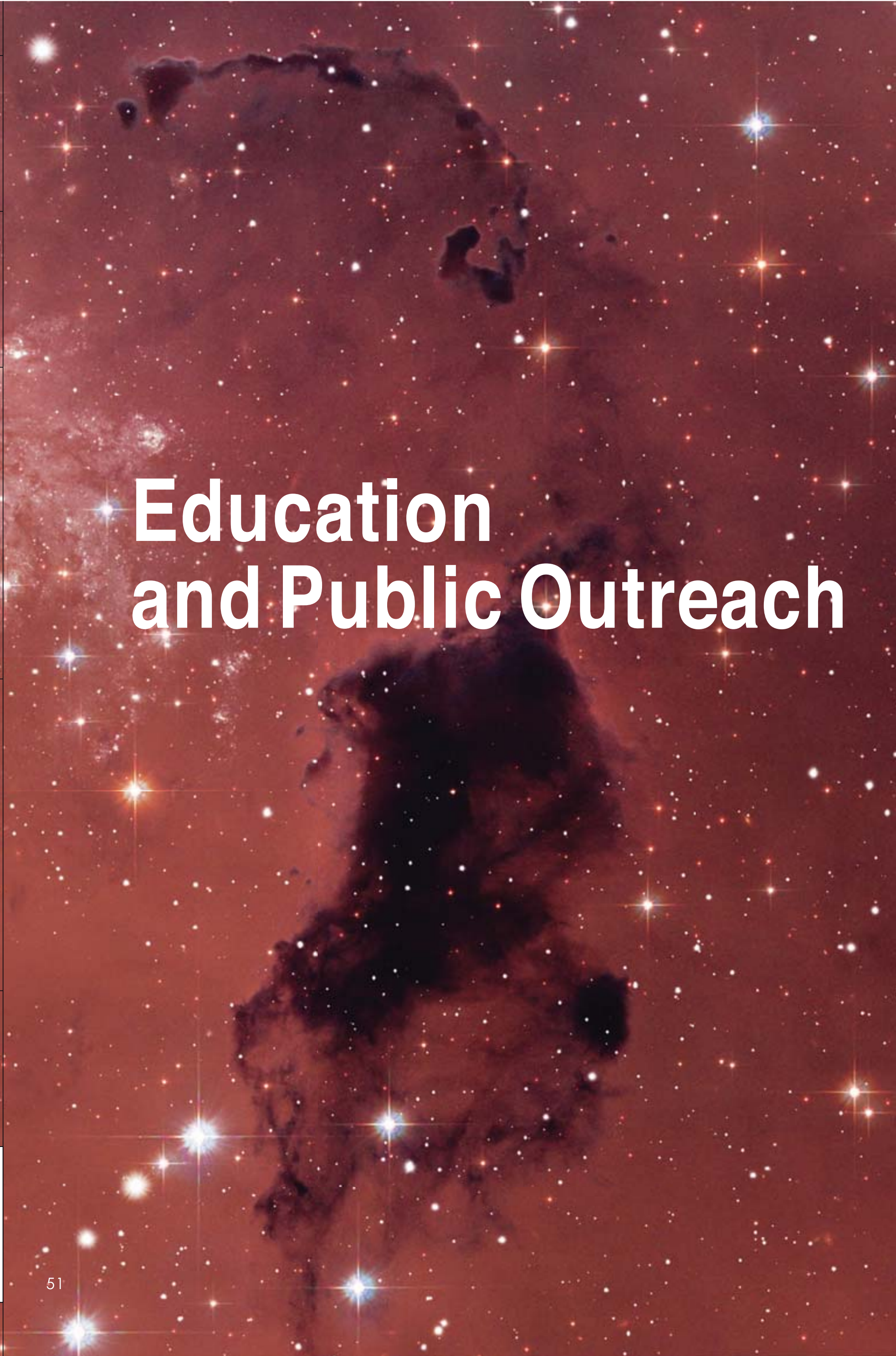
The Canon 10M pixel camera under testing in the lab.

Infrared Array development

Advanced scientific infrared arrays are mainly produced in the US. A collaborative project was proposed by the Advanced Technology Research Laboratory of Chunghwa Telecom (ATR Lab) to develop InGaAs infrared arrays for astronomical applications. Unlike the commonly used HgCdTe sensors, InGaAs technology is much more mature and relatively cheap. The current array that the ATR Lab provides has a cutoff wavelength around 1.7μm with a format of 640 x 480 pixels. Due to the limit of readout IC for normal applications, the array has a relatively high gain and large full limit of readout IC for normal applications well capacity. Initial test results show relatively high dark current and strain pattern at 77^0K. Some improvement has been made for lower dark current and better material strength at cryogenic temperature. We plan to combine the development of CMOS sensor with InGaAs arrays. The low noise CMOS sensor will provide basic circuit for the readout IC of InGaAs array with low background environment and cryogenic temperature.

The 320x256 InGaAs array and the dark image at 77^0K.

We have also been working on quantum dot infrared photodetectors (QDIPs) for a long time. One of the major problems of QDIPs is the lower quantum efficiency due to the limited density of quantum dots (QD) and the wavefunction distribution. New QDIPs structure called confinement enhanced structure was proposed by us to increase the confinement of the electronic wavefunctions in QDs. The result shows a dramatic increase of device efficiency in the conventional dot-in-a-well QDIPs. With this idea, the operation temperature and device performance is greatly enhanced after preliminary optimizing process. A US patent is awarded for the development. Combined with the hybridization capability of ATR Lab, we are developing the focal plane array based on the optimized structure to demonstrate the performance of the new structure. With the possible collaboration of SPICA, OIR Lab also plans to work on far IR detector arrays such as Si:As and Si:Sb detectors. This will further enhance our capability in array testing wavelength from 2.5μm to 40μm. Furthermore, we will have the chance to work on space qualified electronics which will be an important milestone for OIR Lab.



Education and Public Outreach

Education and Public Outreach

Following restructuring of the institute organization after becoming a full institute, the new education and public outreach (EPO) committee is formed from merging former outreach, web, brochure, and library committees. The expansion of public outreach activities at ASIAA is the response to recommendation by the AS 5-year review panel. The EPO 10-member committee is to oversee and provide direction to the outreach activities. Under the Committee, a supporting group is handling daily tasks on publication, public relation, world wide web, educational and promotional activities and collaboration.

Publication

Publication involves producing the ASIAA introductory brochure. Starting from the spring of 2010, we have initiated ASIAA Quarterly to promote ASIAA-led projects, research staff and raise awareness of the value of astronomy. It has A1 format so that at the backside we can put on a poster-size illustration or high-resolution celestial photographs. It has become our platform for introducing ASIAA projects, research results and events. In collaboration with publishing companies each issue is now sent to more than 1,500 high school classes in Taiwan.

We have also published articles to introduce AMiBA, TAOS, and ALMA in magazines, e.g. Taipei Astronomical Museum Magazine, Science Monthly and Physics Bimonthly. There are also an astronomical column in Merit Times and the latest astronomical news for Physics Bimonthly magazine. We also published special issue (leaflets) for senior high school teachers.

2012 Spring Issue front side.

2012 Spring Issue back side.

Public Relation

ASIAA public relation deals with news release and press conferences. We hold press conference whenever there are significant findings led by ASIAA personnel. We have kept a good relation with journalists and occasionally invited them to interview our researchers on ASIAA projects such as Heat Exchanger (HX) and Very Long Baseline Interferometry (VLBI).

World Wide Web

Since October 2003, we have been maintaining a Chinese-language website dedicated to the latest astronomical discoveries. It is to provide a venue for the general public to discover the latest and the most interesting findings in astronomy. We have posted the latest news articles covering a large selection of interesting topics in contemporary astronomy and more than 380,487 visitors have visited as of 2012/8/06. The web server also provides a video-on-demand function to allow users to watch astronomical talks and lectures recorded at Taipei Astronomical Museum and universities. With newly hired staff, we are starting to translate (with permission) NRAO outreach web pages and NASA educational videos, and planning to do CfA websites. There are 27 educational videos by NASA Spitzer Science Center translated into Chinese and put on youtube. ASIAA is also on facebook where we upload the most updated information and photos.

ASWEB

Educational Activity

In educational activity, one of the major events is the annual Academia Sinica Open House in Nangang. ASIAA has always displayed to the public astronomy and astrophysics research in a very animated way. Apart from giving public lectures and displaying posters and exhibits of our research results, we have hands-on activities such as big-bang balloon or simple DIY spectrometer for students to understand astronomy, demonstration of remotely controlling telescopes in Hawaii and on the summit of Lulin Mountain, and “Ask an Astronomer” for visitors to sit down with our astronomers face to face to ask questions about the Universe. To introduce the culture of Hawaii where the ASIAA radio telescopes are located, we have been inviting the Hula Angel club to perform the traditional Hula dance. Thanks to the collaboration on TAOS II with Universidad Nacional Autónomia de México (UNAM), in 2011 we have invited Mexican musicians and a chef for Mexican food for cultural activities. At 2011 Open House there were more than 2,000 visitors to IAA site.

AS Open House. Left : left ASIAA staff is explaining IAA projects to students. Right: Hsiang-Hsu Wang is explaining expansion of the Universe with “big-bang balloon”.

Spinning off from “Ask an Astronomer” of the Open House day, ExploreIAA is another newly-initiated educational activity. Starting in early 2011, the monthly events are held at our building and it is conducted through lively, fun and intimate discussions for a small group of students with our researchers. They are free to ask any questions related to astronomy and astrophysics.

Our astronomers are discussing face to face with students at ExploreIAA events.

Collaboration with local astronomical societies and museums

Since 2010, we have actively participated in the annual Star Party in Wu-Feng of central Taiwan. Star Party is an annual gathering for more than 2,000 astronomy enthusiasts, which is organized by the Astronomy Association of Taichung since 1997. Among the registered participants, roughly half of them are college and high school students. ASIAA has partly sponsored the Star Party since 2010. Apart from handing out ASIAA Quarterly and souvenirs, we have given several lectures on ASIAA projects, frontier research led by ASIAA and other interesting topics including radio astronomy, searching for exoplanets and black holes. Due to the success and popularity, we are now planning on collaboration with societies in southern and eastern Taiwan for small ASIAA open house events.

We are also closely collaborating with Taipei Astronomical Museum, presenting lectures at high schools, hosting visiting teacher and student groups, hosting high-school student projects such as radio telescope DIY, etc. Family Star Club, an organization by parents who are interested in astronomy and assisted by Taipei Astronomy Society, holds a monthly event in ASMAB 1F auditorium, in which we are also providing lectures and talks. In March 2011 we collaborated with National Concert Hall in sponsoring “Sun Rings” by the well-known Kronos Quartet commissioned by NASA Art Program.

ASIAA information desk at 2010 Star Party.

Other personal efforts

There are other personal efforts on publishing popular-science books, articles on magazines, and various educational projects in collaboration with high schools. In order to introduce radio astronomy, a project “Radio Telescope DIY” started in 2008 in cooperation with Taipei Municipal Jianguo Senior High School and had held 4 activities so far. More than 100 senior high school students and teachers participated in this project and they built radio telescopes with commercial satellite dishes (12GHz). Several astronomers are supervising astronomy projects for promising high-school students. We are also in discussion with Dr. Randy Lansberg of Kavli Institute for Cosmological Physics at University of Chicago in utilizing Google Sky database for astronomy projects for high school students.

Summer Student Program

ASIAA officially started the summer student program in year 1998. The goal of the summer student program is to provide the opportunity for students to study selected topics on astronomy, astrophysics and astronomical instrumentation to enrich the undergraduate astronomy program in Taiwanese universities. The students considered by the supervisors are those who are potentially capable and interested in carrying out research or engineering projects in astronomy or astrophysics for their future academic careers. The projects provided by the supervisors in ASIAA cover topics in theoretical astrophysics, numerical simulations on astrophysical problems, radio astronomical observation and data analysis, optical/infrared astronomical observation, observational cosmology, radio astronomical instrument, and even the fabrication and measurement of superconductor devices. From 1998 to 2011, the ASIAA summer student program has trained 186 undergraduate students. Among those students, some returned to ASIAA for advanced research, including two currently as assistant research fellow (Dr. Wei-Hao Wang and Dr. Yen-Ting Lin), and four as postdoctoral fellows (Dr. Mei-Yin Chou, Dr. Li-Jin Huang, Dr. Cheng-Yu Kuo, and Dr. Ya-Wen Tang).

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