ASIAA
Institute of Astronomy and Astrophysics

中央研究院 ACADEMIA SINICA 1928

Contents

Projects

Major Scientific Results

The SAO/ASIAA Submillimeter Array (SMA)

The most important accomplishment of the ASIAA during the previous 3-year period is the utilization of the SMA for science. The ASIAA joined the SMA project in 1996, starting without staff or laboratory facilities. In November 2003, the array of eight 6-m telescopes was dedicated on Mauna Kea by President Y. T. Lee (representing AS) and Secretary Larry Small (representing the Smithsonian Institution). The SMA has since continuously operated as an interferometer at submillimeter wavelengths. In 2004, the first scientific results were published as a special volume in the Astrophysical Journal Letters. In the past two years, some 36 SMA papers were published or submitted. Of these, 29 papers have ASIAA co-authors, and 8 papers have ASIAA first authors.

Figure 1. The SMA project is a collaboration with the SAO, and has benefited from collaborations in Taiwan with university groups and industry. The array is now one of the most important instruments used in the ASIAA for scientific research.

The ASIAA, as a partner on the SMA project, contributes towards the maintenance and operation of the telescopes and receivers on Mauna Kea. The ASIAA has a small local staff residing in Hilo, Hawaii. In addition, the scientific and engineering staff visits the site regularly, and also conducts remote operations from Taipei.

Figure 2. The ASIAA built two of the eight telescopes for the SMA, and has delivered three receiver systems at 230GHz, 345GHz, and 690GHz.

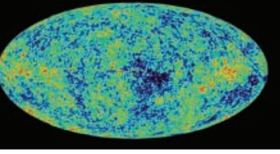
The Taiwan-America Occultation Survey (TAOS)

The majority of trans-Neptunian objects (TNOs) are probably small comets beyond the orbit of Neptune. A study of TNOs may enable a better understanding of the origin of short-period comets and of the process of planet formation and the early history of the solar system. Unfortunately, most of these objects are only a few kilometers in size, hence direct observation of reflected sunlight off them is extremely challenging. Currently, an occultation survey is the only way to detect them at such a large distance.

The TAOS project is a collaboration between the ASIAA, the NCU, the SAO (Alcock group previously at the Lawrence Livermore National Laboratory and the University of Pennsylvania), and the Yonsei University. During the previous 3 years, good progress has been made. Three of the four 0.5m telescopes are now operating on Lu-Lin Mountain with their 2048x2048 CCD cameras tracking some 3000 stars per night, searching for the occultation of a star by any intervening Kuiper Belt Objects. The fourth telescope, from Yonsei, has been installed, and is close to operations.

Figure 3. Left: One of the TAOS 0.5m telescopes in its enclosure. Right: The four TAOS telescopes on top of Lu-Lin Mountain. Two of them are in the foreground. (Picture credit: S. K. King and H. C. Lin)

The TAOS telescopes can be operated remotely, after the enclosures are opened by a resident assistant on site. By having multiple telescopes with varying baselines, we can reject spurious signals due to the atmosphere and equipment, by coincidence arguments. Some 100 million stellar photometric measurements have now been made. Upgrades to the cameras are being planned to increase the sensitivity of the surveys.



The Array for Microwave Background Anisotropy (AMiBA)

The Array for Microwave Background Anisotropy (AMiBA) is a forefront instrument for research in cosmology. This project is led, designed, constructed, and operated by ASIAA, with major collaborations with National Taiwan University, Physics Department (NTUP), Electrical Engineering Department (NTUEE), and the Australia Telescope National Facility (ATNF). Contributions also came from the Carnegie Mellon University (CMU), and the National Radio Astronomy Observatory (NRAO).

As a dual-channel 85-105 GHz interferometer array of up to 19 elements, AMiBA is designed to have full polarization capabilities, sampling structures greater than 2 arc minutes in size. The AMiBA targets specifically the distribution of high red-shift clusters of galaxies via the Sunyaev-Zel'dovich Effect (SZE), as a means to probe the primordial and early structure of the universe. AMiBA will also measure the polarization properties of the Cosmic Microwave Background (CMB), which is sensitive to the ionization history of the universe and can be a potential probe for gravity waves. It will improve upon the recent results from WMAP by a factor of 10-20 in angular resolution.

AMiBA is sited on Mauna Loa in Hawaii, at an elevation of 3,300m to take advantage of higher atmospheric transparency and minimum radio frequency interference. The construction of AMiBA includes a novel hexapod mount, a carbon fiber platform, MMIC receivers, broadband digital correlators, and of course software development. We project a sensitivity of ~2 mJy with the 1.2m elements in 1 hour. This will allow us to detect and map 20-50 clusters of galaxies every year. The project involves extensive international and domestic scientific and technical collaborations. Currently, the AMiBA is deploying the initial 7-element interferometer in Hawaii. An expansion to the 13-element configuration is underway, to be followed possibly by an expansion to 19-elements. We expect to start operations and testing in 2006.

Figure 4. The AMiBA is near completion on Mauna Loa. In 2005, the carbon fiber platform was mated with the hexapod mount. Receivers and correlator are being installed at the moment.

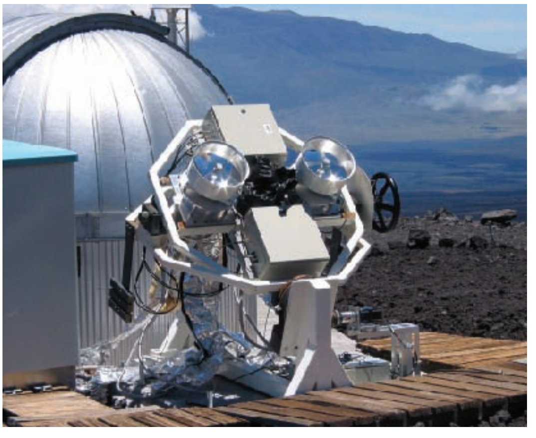
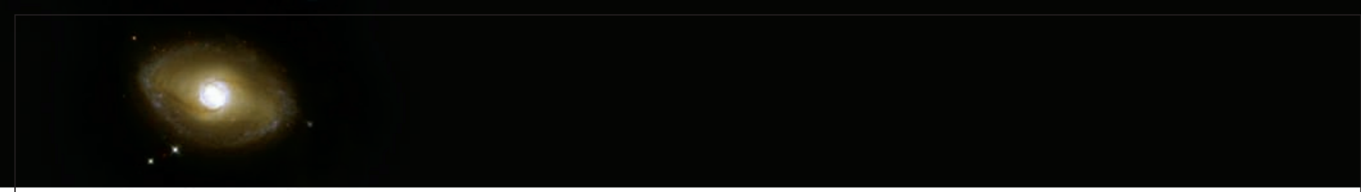


Figure 5. A 2-element prototype was deployed to Mauna Loa in Hawaii in 2002.



The Computational Fluid Dynamics and Magnetohydrodynamics Project (CFD/MHD)

CFD-MHD initiative has been a joint research project of the Institute of Astronomy and Astrophysics (ASIAA) and the Institute of Mathematics (ASIM) of the Academia Sinica, and the Department of Mathematics of the National Taiwan University. Its main goal is to develop high-performance codes of computational fluid dynamics and magnetohydrodynamics (CFD-MHD) for astrophysical problems. Over the last 4 years, we have successfully developed a set of 2-D Godunov codes based on exact Riemann solver. They are featured with self-gravitation and characteristics decomposition on the boundary, guaranteed non-reflection. At present we are applying these codes to the study of two main problems: the structure and evolution of gas disks in spiral galaxies and the planet migration in protostellar disks.

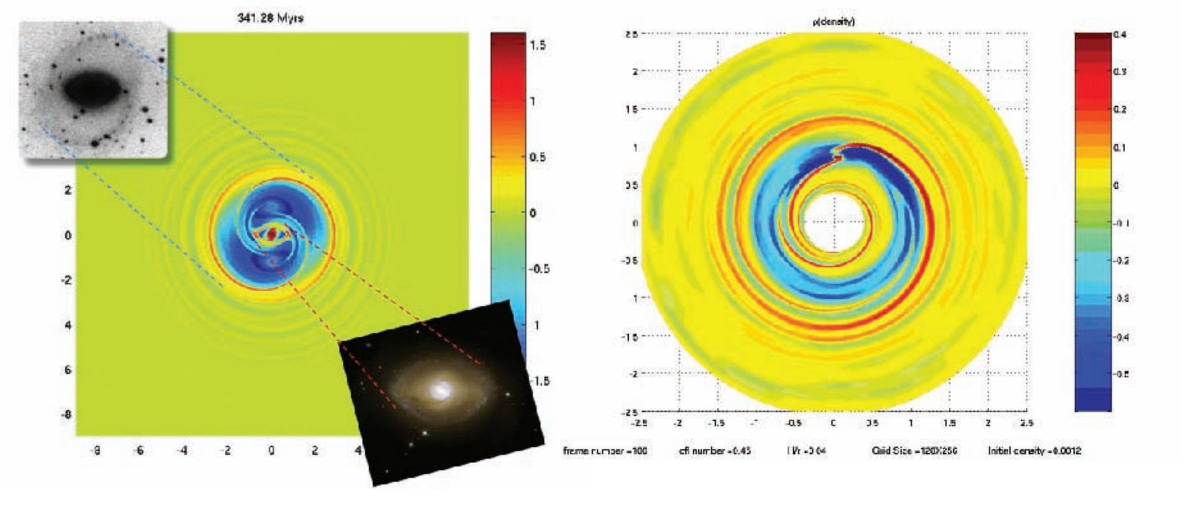
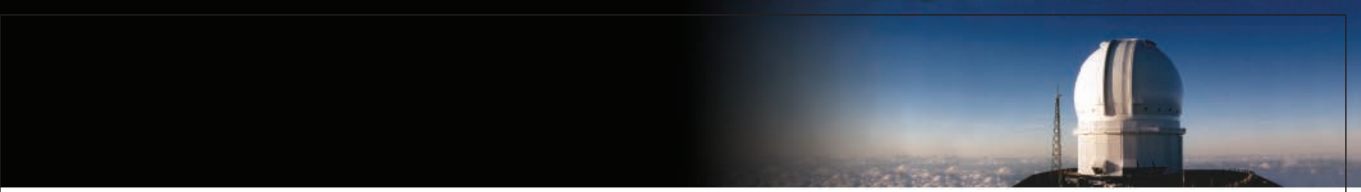


Figure 6. The CFD/MHD team is developing a high performance numerical code to study the structure formation in disk galaxies. Numerical simulations have successfully reproduced the spiral arms excited by stellar bars, such as the ones seen in NGC 6782 (left panel). We have also shown how a Jupiter-size planet embedded in a self-gravitating proto-planetary disk can clear a gap and migrate to the center (right panel).



The Optical and Infrared (OIR) Instrumentation Program

In order to support follow-up observations of high-redshift clusters detected with the AMiBA project and to train the next generation of OIR astronomers, ASIAA negotiated for 68 nights of observing time on the 3.6m Canada-France-Hawaii Telescope. This is part of the CosPA effort together with the AMiBA development. Financial contribution from ASIAA is in the form of support for the development of the Wide Field Infrared Camera (WIRCam). This camera has four 2048x2048 HcCdTe detector arrays, with a 20' field of view, and 0.3" pixels. The camera is cooled to liquid nitrogen temperatures to suppress the infrared background. In 2005, the WIRCam was installed on CFHT, and commissioned.

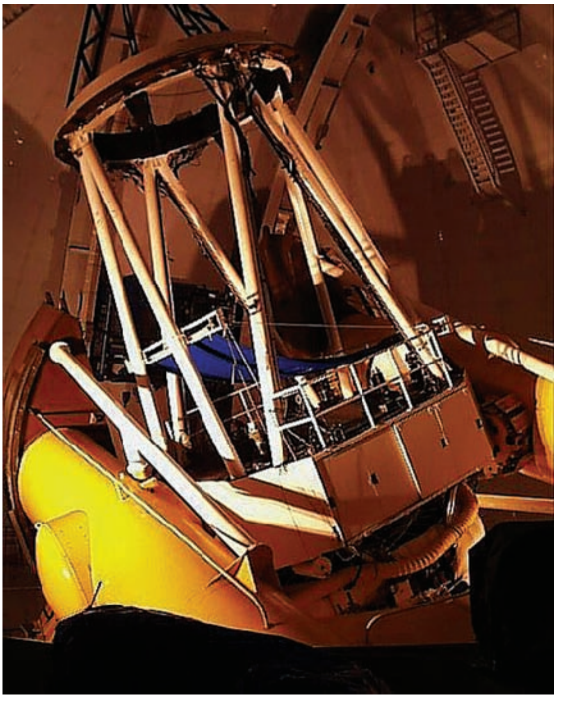


Figure 7. Left: The 3.6m CFHT in its dome on Mauna Kea. Right: The WIRCam was completed and installed on the CFHT during 2005. Commissioning and testing are underway.

Building on our experience with TAOS, the WIRCam project further developed the capability at the ASIAA to build world class optical and infrared instruments. The ASIAA staff participated in the specification and contracting of the subsystems, the assembly and testing of the camera, and also the development of the array control electronics. With the delivery of WIRCam, the ASIAA will move to the next instrumentation project, likely the implementation of a new adaptive optics system on CFHT.

Extragalactic Studies

One of the important directions for the extragalactic group has been the study of interacting systems using HI observations on the VLA, and CO observations with BIMA and the SMA. Active Galactic Nuclei (AGNs) and Quasi-Stellar Objects (QSOs) are believed to be the luminous visible evidence for the vigorous accretion of gas onto central supermassive black holes. What triggers the nuclear activity of these galaxies; i.e., what mechanism brings the fresh supply of fuel required to feed their central supermassive black holes? Tidal torques produced by gravitational interactions between galaxies can force large amounts of gas into the centers of galaxies, but studies reveal that the majority of active galaxies appear to be otherwise normal in optical starlight. Observation in atomic hydrogen (HI) gas, which is the most sensitive tracer of tidal interactions between galaxies, is starting to change our views of these galaxies. In HI images of QSO host galaxies reveal tidal features produced by gravitational interactions with neighboring galaxies, features not seen in optical starlight. This study has been extended to Seyfert galaxies, with the same results. Study of nearby Seyfert galaxies are being pursued with the SMA to map the distribution of denser and warmer molecular gas, as traced in the higher transitions of the CO line, in the inner regions of these galaxies.

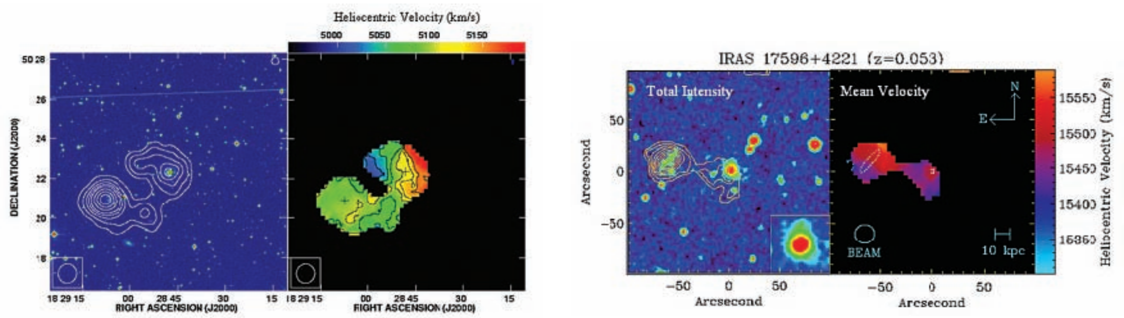


Figure 8. Our systematic HI imaging studies of Seyfert galaxies harboring luminous AGNs and QSOs with the Very Large Array (VLA) show that the majority exhibit HI tidal features or disturbances in both morphology and kinematics tracing interactions with neighboring galaxies. The above panels show two examples, the Seyfert galaxy AKN 539 (left: Kuo et al. in preparation) and the QSO host galaxy IRAS 17596+4221 (right: Lim & Ho, 1999, ApJ, 510, L7).

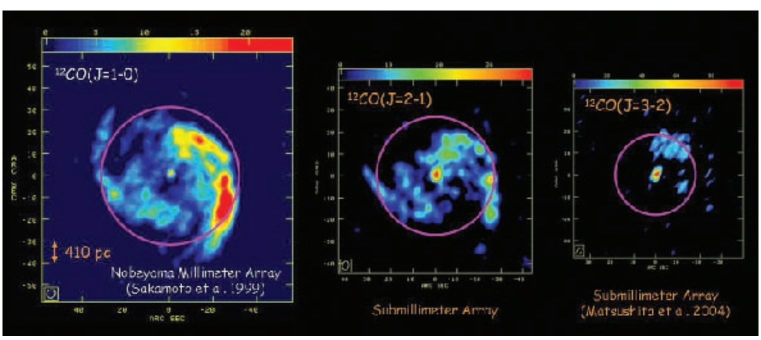


Figure 9. Multi-transition CO observations toward the Seyfert 2 galaxy M51 show stronger intensity toward the nucleus in the higher CO transitions. This result suggests that the molecular gas around this Seyfert 2 nucleus is dominated by denser and warmer molecular gas. The CO(J=1-0) image is taken from Sakamoto et al. (1999, ApJS, 124, 403) and the CO(J=3-2) image is taken from Matsushita et al. (2004, ApJ, 616, L55).

Galactic Center

The presence of the supermassive blackhole SgrA* in the Galactic Center has driven some of the studies carried out at the ASIAA. One long term project has been the attempt to resolve the radio continuum emission from SgrA* by using VLBI techniques. The key is that the synchrotron emission continues to be dominated by interstellar scattering effects even at 1.3cm. However, scattering is minimized at 7mm and 3mm, where some structure is beginning to emerge. The latest VLBA results reported in Nature, shows a radio image of SgrA* at 3mm. This work demonstrates that an object of approximately four million solar masses is confined within 1 AU. It provides the strongest evidence that SgrA* is a supermassive black hole. Another project has been to study the environment at the scale of 1pc around the central black hole. There are hints of infalling gas which appears to be heated as it gets closer to the central region. The SMA is being used to study the central few parsecs in a variety of high excitation lines.

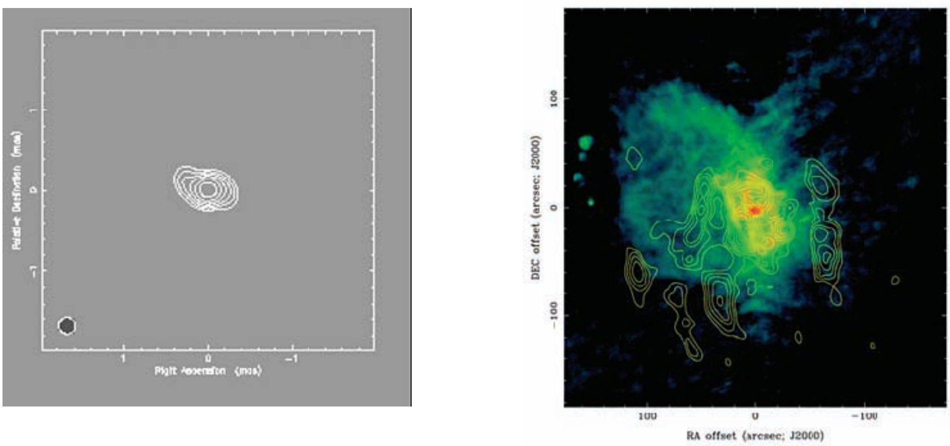


Figure 10. Left: Highest resolution (0.0002") image ever obtained of the Galactic Center via VLBA observations at 3mm. The slight extension in the east-west direction shows that emission is resolved at 20 Schwarzschild radii from the central supermassive black hole. Right: Image of the central 1pc region of the Galactic Center shows a concentration of hot gas traced by an ammonia emission line contours with the VLA. This may be material being accreted towards the central region of the Galaxy. (Left: Shen et al., 2005, Nature, 438, 62; right: Herrnstein & Ho, 2002, ApJ, 579, L83)

Galactic Star Formation Studies

The advent of the SMA has made enormous contributions to the study of star formation. The spectrum in the submillimeter is very rich and many molecular lines can be studied at once along with the dust continuum emission. With the aid of other radio instruments, the ASIAA is engaged in studies of: (1) debris disks around young stars which may illuminate our understanding of planetary formation; (2) circumstellar jets which can be traced in the submm much closer to their launching sites near their exciting sources; (3) magnetic field structures at sub arc-second resolutions via polarized dust emission; (4) molecular outflows whose interactions with their surroundings are traced in a variety of spectral lines; and (5) collapse and fragmentation in cloud cores by studying their kinematics and morphology.

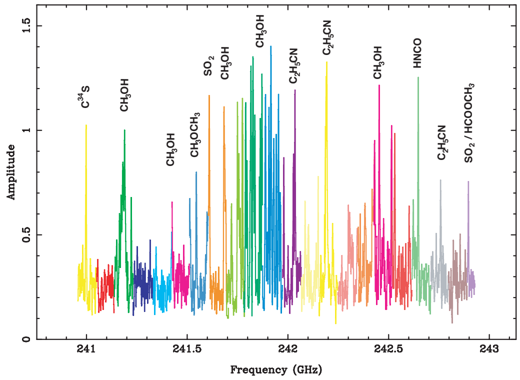
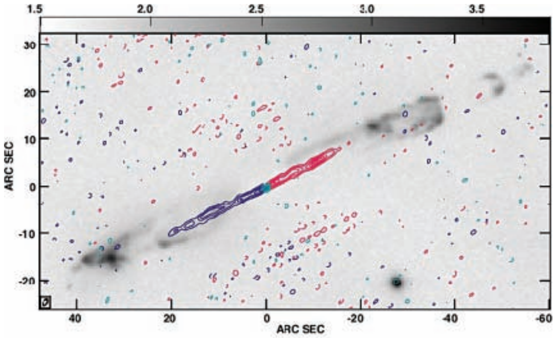


Figure 11. A typical SMA spectrum shows a forest of spectral lines from many molecules, which allows detailed studies of the chemical and excitation conditions. (Su et al., in preparation)

Figure 12. The SMA image of the blueshifted and redshifted SiO J=5-4 emission from the HH211 protostar outflow, superposed on the NIR H2 image observed with the VLT. The emission seems to come from the narrow jet-like region with its approaching part in the east and receding part in the west of the obscured young star. The SiO jet consists of a chain of knots separated by 3-4" (~1000 AU), aligned with a series of faint H2 knots. This suggests that the mass ejection from the central young star is time variable. (Hirano et al., ApJL, in press)



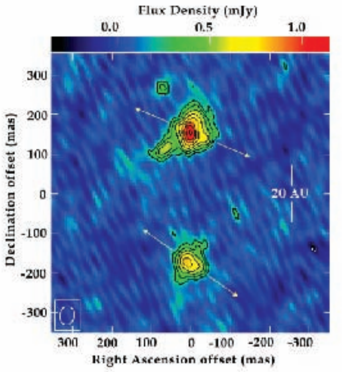


Figure 13. Radio image of the protostellar system L1551 IRS5 taken at 7mm with the VLA and the PT antenna. The two pairs of arrows indicate the orientation of twin bipolar ionized jets. The circumstellar dust disks (orthogonal to the jets) of the two main components are nearly perfectly aligned. A possible third component lies just 11 AU to the sourth-east of the northern component. (Lim & Takakuwa, 2005, submitted)

Solar System and Stellar Studies

With TAOS now operating, KBO survey is underway. Simultaneous measurements by multiple telescopes eliminate systematics and confirm possible detections. Tests on known occultation events work. Some 100 million monitoring measurements have been made. The ASIAA has a strong group in evolved star. The synthesis of complex organic and inorganic compounds is being studied through rotational transitions with mm and submm telescopes, and through the stretching and bending modes using infrared telescopes in space. Mid-infrared imaging of planetary nebulae and proto-planetary nebulae is being carried out at Gemini Telescope and spectroscopic scans of evolved stars is underway at the Arizona 12m mm telescope and 10 m submm telescope to study circumstellar chemistry.

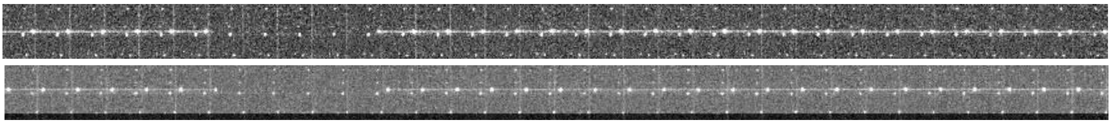


Figure 14. TAOS zipper-mode image of the occultation of HIP050525 (m_V~8.46mag) by the asteroid (1723) Klemola (m_V~15.7mag;D~31km). Each frame is a 0.25 second read out of the field. Some 10^8 stellar photometric measurements have now been made in this mode. (King et al., Advances in Geosciences 2005, in press)

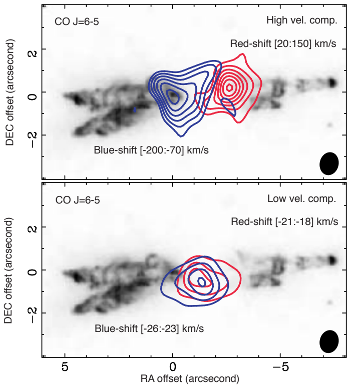


Figure 15. The CO J=6-5 line of the proto-planetary nebula CRL 618 is first imaged by the SMA. Two different kinematical components, which are interpreted as high (upper panel) and low (lower panel) velocity bipolar outflows, are seen in Figure 15. The background is the HST WFPC2 optical image from Trammell & Goodrich (2002). (Nakashima et al., in preparation)

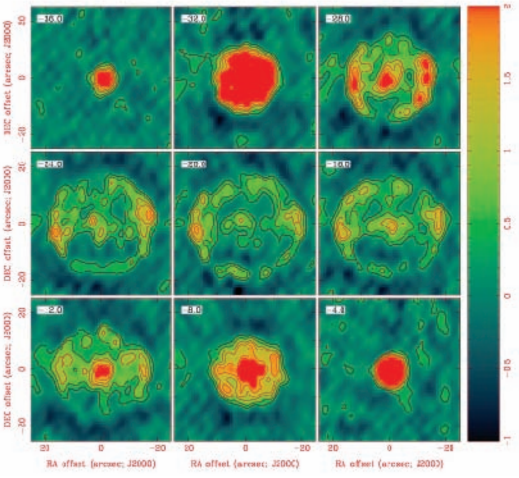


Fig 16. R Sculptoris (R Scl) is a carbon star known to have a young detached shell, presumably created during a very short period of intense mass loss. The CO J=2-1 emission imaged with the SMA shows a very clumpy shell at a radius of ~20", which closely matches the dust shell seen in scattered light. This shell has a dynamic time scale of ~1600 years. The emission closer to the center represents a more recent episode of mass loss. (Dinh-V-Trung et al., in preparation)

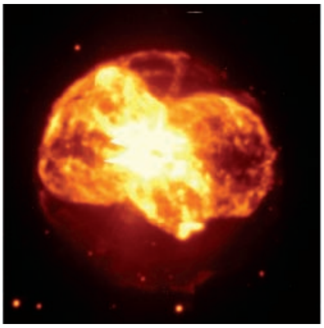


Figure 17. Although many planetary nebulae are known to have bipolar structures, some are now found to be multipolar. This CFHT NII image of NGC 2440 shows that it possesses 3 pairs of bipolar lobes within the spherical halo. (Picture credit: Sun Kwok & Kate Yu-Ling Su)

Cosmology

In support of the AMiBA project, a cosmology group is being assembled at ASIAA. Efforts have concentrated on calculating and modeling what might be detected with AMiBA. The polarization properties of the CMB, as measured from its power spectrum, have been simulated and compared to theoretical predictions. For detecting clusters via the SZ effect, the expected signals have been simulated in order to drive the design of the AMiBA observations. In addition to AMiBA studies, the cosmology group also makes use of other instruments such as the Subaru and the CFHT to pursue optical studies of distant clusters. The weak gravitational lensing effect, which distorts the background galaxies, can be used to deduce and model the cluster mass distribution in the foreground.

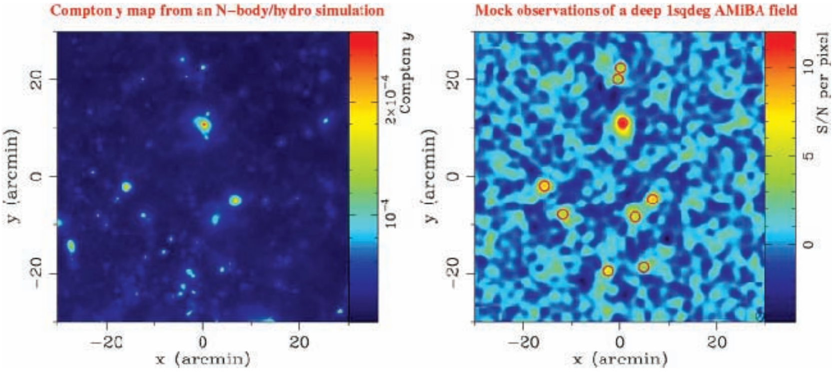


Figure 18. The figure demonstrates a simulated deep SZ cluster survey with the 19-element AMiBA based on cosmological N-body/hydro simulations. The left panel shows an input Compton y map of 1 square degree, and the right panel shows mock AMiBA observations of the same piece of sky in a deep survey of 270 hours. Cluster detections above 4 sigma (=2.4mJy/beam) are indicated by red circles.

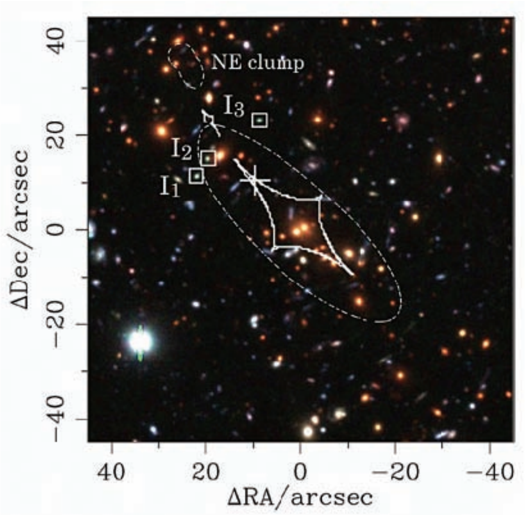


Figure 19. Subaru/Suprime-Cam image of the distant cluster RXJ0152 at z=0.83. The caustic of the gravitational lens due to the cluster is indicated by the thick white line. The predicted amplification and images of a background galaxy at z=3.8 (cross), fits nicely the spectroscopic and imaging observations of I_1, I_2, and I_3. Such lensing studies are useful probes of cluster mass distributions. (Umetsu et al., 2005, PASJ, 57, 877)

Gas Dynamics

In the past few years, an effort has been put into developing gas-dynamic codes for studying the effects of a periodic driving force on the evolution of gaseous disks. We have successfully applied this code to the basic fluid dynamics of gas disks in galaxies. Our primary focus is on the external potential due to a stellar bar rotating at a constant angular speed. Among the theories invoked to explain the spiral structures in galaxies, the density wave theory is perhaps the best motivated and most widely accepted. With our simulations, we hope to be able to lend further support to it and fill in more of its details. This code is also instrumental in the study of protoplanetary disks. Our simulations show that giant planets can form far from their suns, and migrate inward via interaction with the gas disk.

In addition to developing our own codes, a separate team has been using the Zeus codes for investigating the collapse of molecular clouds in star formation, as well as the formation of MHD jets, winds, molecular outflows and star-disk interactions.

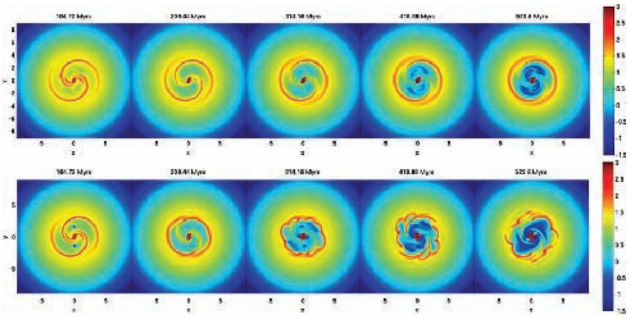


Figure 20. Simulations of the 3-kpc arm in the Milky Way generated by density waves excited by the bar potential. Top Panel: Formation of spiral arms ignoring self-gravity from the gas. Bottom Panel: Same simulation including self-gravity. The spiral arms become unstable. (Yuan & Yen, in preparation)

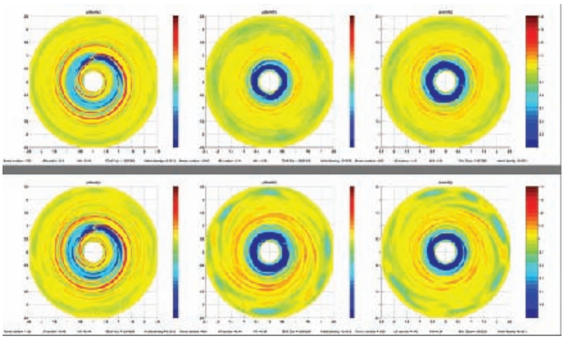


Figure 21. Simulations of protoplanetary disks with one giant planet. Top row: evolution of the gas disk without self-gravity. Bottom row: Self-gravity of the gas is included. (Zhang, Yuan & Yen, in preparation)

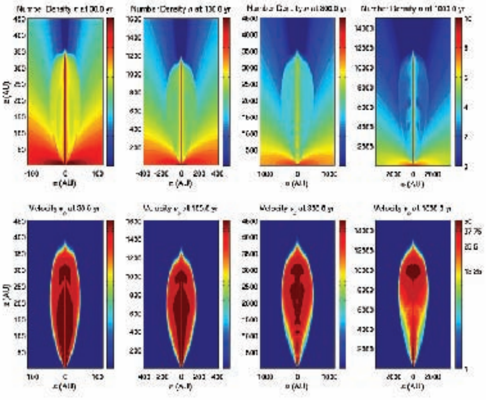


Figure 22. Formation of molecular outflows by a wide-angle wind with jet-like density stratification, closing the gap for the long-debated jet-driven and wind-driven origins of molecular outflows. The density and velocity structures along and across the jet and the outflow lobes are evolved numerically. Such framework can be compared with the SMA results from HH211 presented in Figure 12. (Shang et al., 2006)

Optical Astronomy

With the implementation of WIRCam on CFHT, widefield images are now possible. The ASIAA staff has conducted a number of experiments on CFHT, not only in support of AMiBA cluster studies, but also for other astrophysical problems. CFHT provides access to a large optical telescope for the astronomers in Taiwan. The ASIAA aims to continue to secure access to CFHT through a collaboration to develop Adaptive Optics.

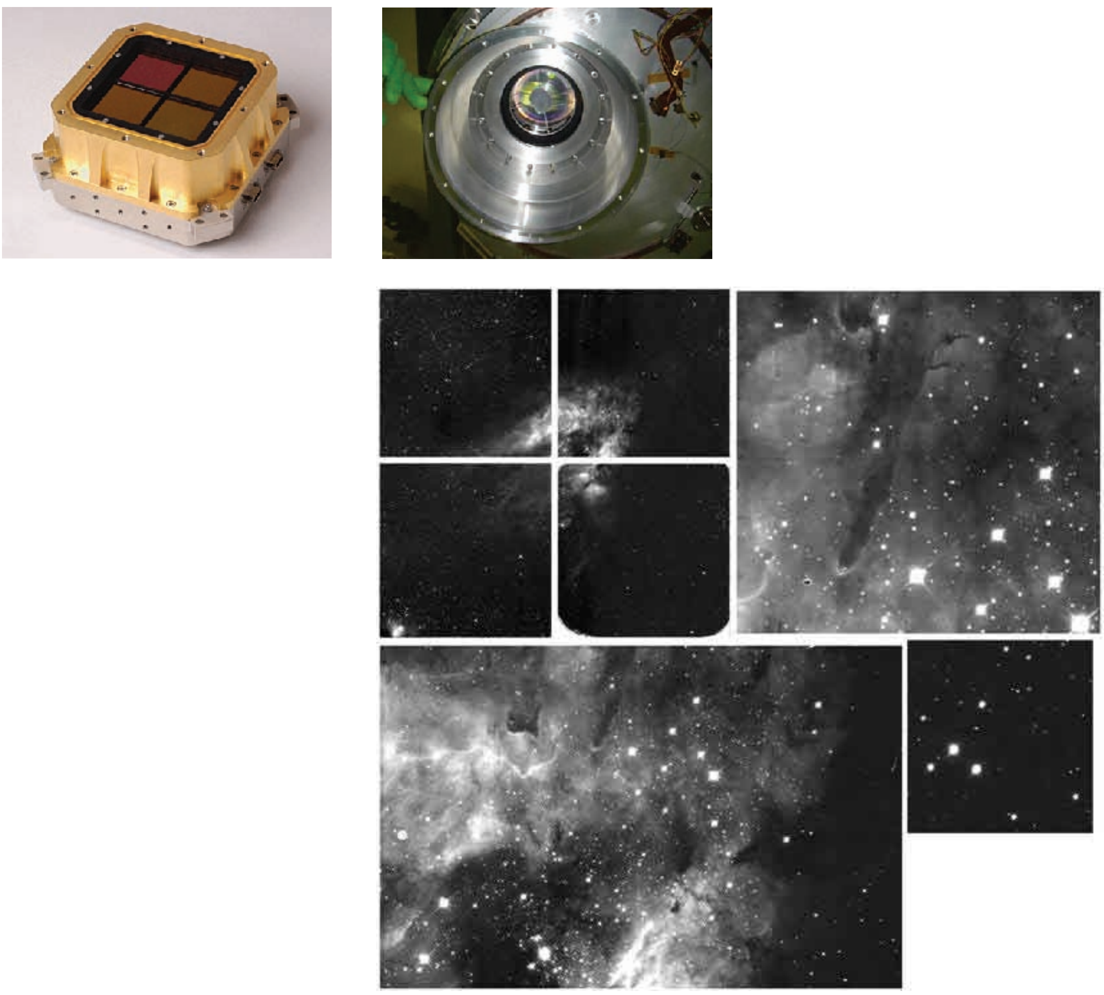


Figure 23. Top: The four WIRCam detector arrays being incorporated into its cryogenic dewar. Bottom: The four side-by-side images obtained by WIRCam on the CFHT. The mosaic of images of the M17 star forming region shows the wide field coverage of this camera, which is a vast improvement for the infrared.

Instrumentation Research

In the past decade, a millimeter-submillimeter wavelength receiver group has been assembled in order to support the instrumentation for the SMA and AMiBA project. This has meant the development of the capability to make SIS junctions up to 690GHz. The SIS junction development also takes advantage of superconductor research in Taiwan, with collaborations with the AS Institute of Physics and National Tsinghua University physics department. The ASIAA also built all the cryogenic systems, the electronics, Millimeter wavelength Integrated Circuit (MMIC) devices, digital correlator, readout chips, via collaboration with the EE department of National Taiwan University. There is also a collaboration with NRAO to produce photonic calibration systems.

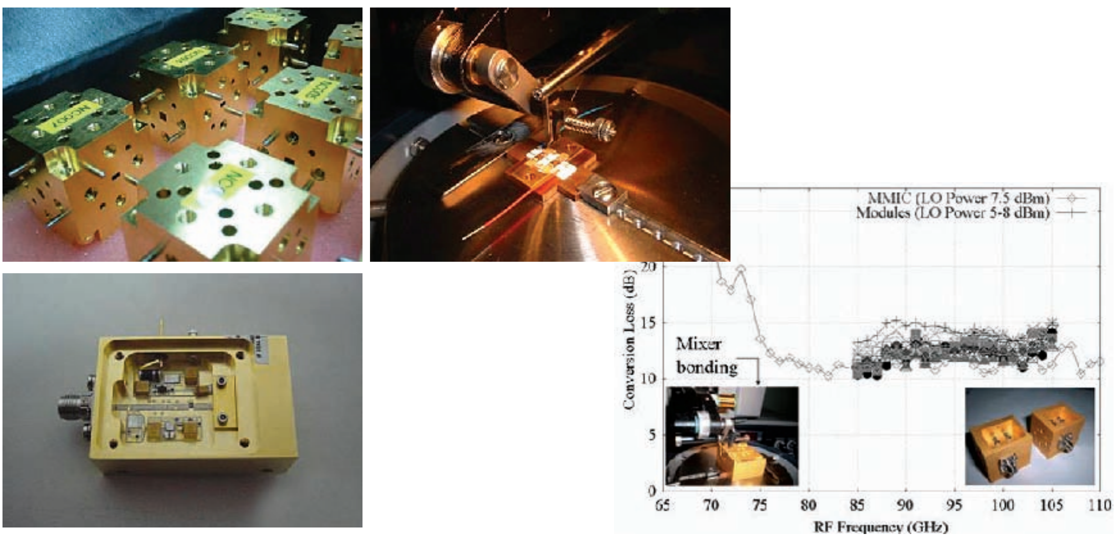


Figure 24. Clockwise from top left. Devices built for AMiBA: production noise couplers, subharmonic mixer, amplifiers used in the four-way power dividers, production GaAs HEMT doubler modules.

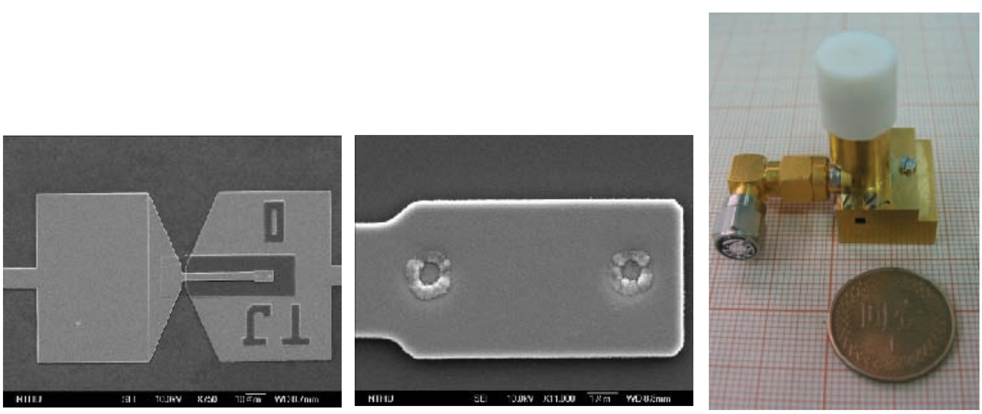


Figure 25. Left: The SEM picture of the 690GHz mixer fabricated at Taiwan. Right: The 690GHz mixer block.

picture credit:

SMA
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David Aguilar, CFA

TAOS
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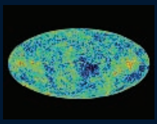

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