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Astronomy Research in China

Jingxiu Wang

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China. e-mail: wjx@ourstar.bao.ac.cn

Abstract. Decades of efforts made by Chinese astronomers have established some basic facilities for astronomy observations, such as the 2.16-m optical telescope, the solar magnetic-field telescope, the 13.7-m millimeter-wave radio telescope etc. One mega-science project, the Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), intended for astronomical and astrophysical studies requiring wide fields and large samples, has been initiated and funded.

To concentrate the efforts on mega-science projects, to operate and open the national astronomical facilities in a more effective way, and to foster the best astronomers and research groups, the National Astronomical Observatories (NAOs) has been coordinated and organizated. Four research centers, jointly sponsored by observatories of the Chinese Academy of Sciences and universities, have been established. Nine principal research fields have received enhanced support at NAOs. They are: large-scale structure of universe, formation and evolution of galaxies, high-energy and cataclysmic processes in astrophysics, star formation and evolution, solar magnetic activity and heliogeospace environment, astrogeodynamics, dynamics of celestial bodies in the solar system and artificial bodies, space-astronomy technology, and new astronomical techniques and methods.

1. Introduction

At this time when we are seeing the dawn of the new century, Chinese astronomers are facing great opportunities and challenges, as well as great difficulties.

Generally speaking, astronomy is an observational science. Its glamour and influence lie in new observations and observational discoveries. Progress in astronomy research heavily depends on the advanced instrumentation and technology, which are expensive and require continuous innovation. It is not appropriate to talk about astronomy research in China without mentioning its weaknesses. The ground-based instruments, developed by Chinese astronomers, are of small and, at most, medium sizes. The biggest optical telescope in China, 2.16 m, was put into operation in early 1990s forty years after the 5.7-m Hale Telescope on Palomar Mountain started to work in the U.S. So far, no Chinese satellite has yet been launched for astronomical observations. The funding level for Chinese astronomy research is less than one tenth of that in developed coun-

tries. There are few world-renowned Chinese astronomers. Some of our brilliant young graduate students and qualified astronomers continue to drain into developed countries. A detailed analysis of Chinese astronomy can be found in a report by Su et al. (1997).

With such a difficult situation, our long-term goal in astronomy research raises several questions: what can Chinese astronomers do in the foreseeable future? what are their strategic considerations? what would they like to share with, and contribute to the international astronomy family? With regard to these questions, two events are indicative. First a mega-science project, Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST), intended for astronomical and astrophysical studies requiring wide fields and large samples, has been initiated and funded. Secondly, the National Astronomical Observatories (NAOs) of China have been coordinated and established by the Chinese Academy of Sciences. Chinese astronomers have set up their goals, and are poised to make their contribution to a more comprehensive understanding of our universe and all of its components.

2. Basic Observational Facilities

Chinese astronomers have dreamed and worked generation by generation to lay their own foundation of astronomical observations. They clearly understand that, although the facilities they established might be very limited, they are most important not only for frontier studies of carefully-selected topics, but also for training astronomers who will be ready to work later with more advanced facilities. Indeed, developing one's own instrumentation creates a group of astronomers who gain knowledge of both the science behind the observations and the techniques used for the observations, is created. Decades of efforts made by Chinese astronomers have established some basic facilities, mostly for common purposes (see Table 1).

Table 1. Key Commonly-Used Astronomical Instruments in China

Wavelength	Diameter	Location	Main science
Optical	2.16	*Xinglong (NAOs)	AGN, stars, galaxies
Optical	1.56	Sheshan (ShAO)	astrometry, Galaxy
Optical	1.00	Kunming (NAOs)	AGN, stars
Infrared	1.20	Xinglong (NAOs)	infrared photometry
Millimeter	13.70	*Delinha (NAOs & PMO)	star formation
Meter	28×9.00	Miyun (NAOs)	meter source survey
Radio	25.00	*Sheshan (NAOs & ShAO)	VLBI observations
Radio	25.00	*Urumqi (NAOs)	VLBI observations
solar	.35	*Huairou (NAOs)	vector magnetograph

* Observing base of NAOs, Southern Base will be at Lijiang in Yunnan
PMO – Purple Mountain Astronomical Observatory
ShAO – Shanghai Astronomical Observatory

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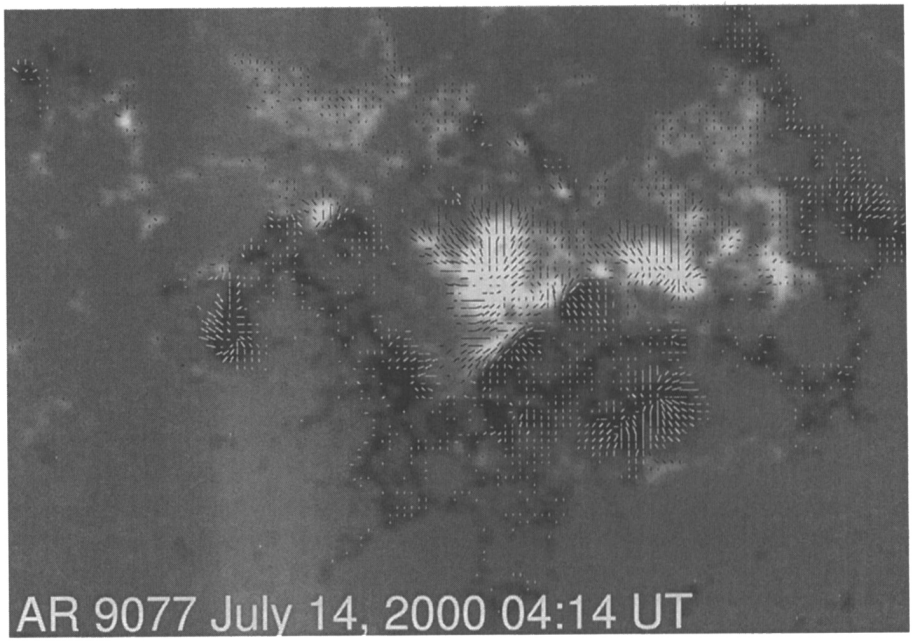

Figure 1. Vector magnetogram of AR9077, one of the most active regions in this solar cycle. The line-of-sight component is represented by brightness, with darker (lighter) color for negative (positive) polarity; the transverse components are presented by short line segments with their length proportional to field strength and alignment parallel to the field direction. Courtesy J. Zhang and Y. Deng

The majority of these instruments are operated by the National Observatories in the Chinese Academy of Sciences (CAS). They are accessible to researchers from both CAS and universities. The scientific output of the facilities is considered satisfactory. For example, 30 papers were published in SCI source journals based on the observations with the 2.16-m telescope in 1999. The 2.16-m telescope is actively involved in international campaigns on AGN and pulsating stars. The majority of its observating proposals focus on AGN, starburst galaxies, normal galaxies, supernova, metal-poor stars, pre-main sequence stars, pulsating stars, and coronally active stars. Based on observations from the 1-m telescope at Kunming, great progress has been made on the observational studies of BL Lac objects. The Solar Magnetic Field Telescope at Huairou has produced some of the best vector magnetograms for solar activity studies. One vector magnetogram is shown in Figure 1 for a superactive region, AR9077, observed in July, 2000.

Except for the key instruments of common purpose, some specific instruments are operated by research groups. To list a few, an old 60/90 Schmidt telescope equipped with 2K×2K CCD is effectively used for multiple-color surveys of large-red-shift galaxies by a leading group from NAOs; a 60-cm reflector, adapted as a specialized telescope for supernova (SN) monitoring at Xinglong

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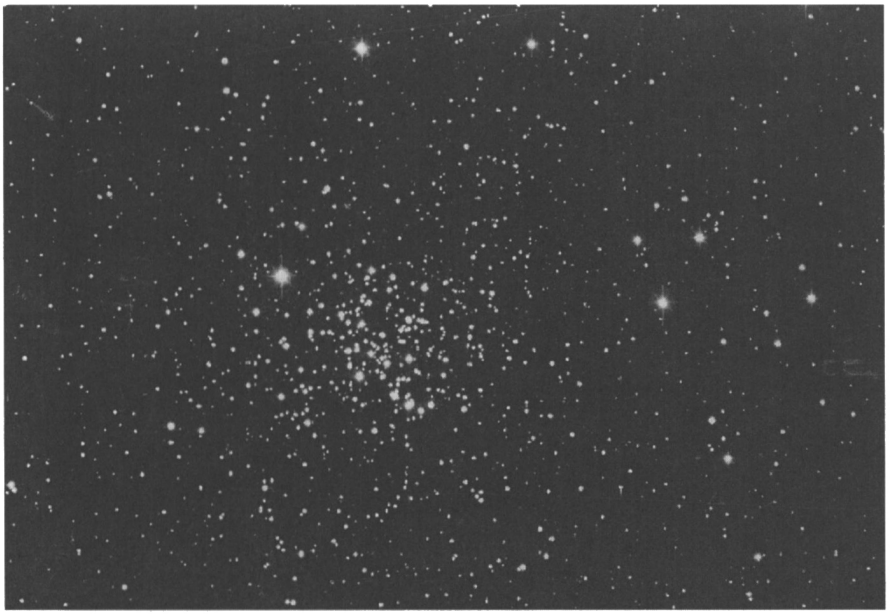

Figure 2. A image of the well studied galactic open cluster M67. The image is made by composition of three images at 8490A (red), 6075A (green) and 3890A (blue)Å. Courtesy L. Deng and the survey team

Station of NAOs – one of the best systems for SN survey – has captured 35 bright supernovae from early bursts in the last three years; A 50-cm solar-spectrum telescope is working on Stokes polarimetry in another research group of NAOs at Kunming. Those telescopes are really small, but specialized for a particular scientific topic and combined with intelligence from leading scientists. Therefore the scientific returns from these small telescopes are impressive. Figure 2 is an example of the deep-sky survey images of the galactic open cluster M67, the deepest view so far for this open cluster.

So far, in Chinese universities there has been one advanced telescope, the 60-cm solar-tower telescope equipped with an imaging spectrograph of multiple wavelengths. A leading group from the Astronomical Department of Nanjing University has made important progress in the studies of semi-empirical models of solar flare and sunspots based on the observations from this telescope.

3. Major Initiatives

As a developing country, China certainly lacks the capability to invest heavily in astronomy. The Chinese Academy of Sciences has worked out a way for major initiatives. It has been suggested to the country to sum up the available funds, and in each 5 years to open an opportunity for a mega-science project. Chinese astronomers seized a chance in early part of 1990s, and had a national mega-science project, Large Sky Area Multi-Object Fiber Spectroscopic Telescope

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(LAMOST), approved by the State Planning Committee of China in 1997. The concept of LAMOST is described by Wang et al. (1996).

LAMOST is a meridian reflecting Schmidt telescope laid on the ground with its optical axis fixed in the meridian plane. Since it is aimed at the scientific goal of "wide field-of-view and large samples", it adopts a simple meridional structure, so that the telescope, being stationary on the ground, can be very long and thus, since it is a Schmidt-type telescope, have a broad field-of-view. The other two essential factors for the telescope, correction of spherical aberration and tracking corrections, are effected by the ingenious introduction of an active reflecting corrector. The aperture of LAMOST is 4 m, enabling it to obtain the spectra of objects as faint as 20.5 magnitude with an exposure of 1.5 hours. Its focal plane is 1.75 m in diameter, corresponding to a 5° of field-of-view, and may accommodate as many as 4000 optical fibers. So the light from 4000 celestial objects will be led into a number of spectrographs simultaneously. Thus, the telescope, when complete, will have the highest spectrum-acquiring rate in the world. In technique and technology, the active reflecting corrector not only plays a key role in the design of LAMOST, but also presents itself as a significant innovation for the further development of modern astronomical instruments.

LAMOST will be located at Xinglong Station of NAOs. It will be open to the world-wide astronomy community. The budget for this project is RMB 235 M Yuan (about U.S. $28 million. It will come into operation at the end of 2004. LAMOST will bring Chinese astronomy to a frontier position in large-scale observations of optical spectra, and in wide-field astronomy.

Several other major projects are under active study and preparation for future selection as national mega-science projects. Among them, an astronomy satellite, e.g., Space Solar Telescope (SST) and a ground-based Five-hundred meter Aperture Spherical Telescope (FAST) are most attractive and promising. SST is aimed at observations of solar magnetic activity at the fundamental spatial scale, i.e., 75 km on the solar surface. FAST will be the largest single-disc radio telescope. The ultimate goal of the major initiatives is greatly to strengthen the observating facilities for Chinese astronomy.

Coordinated with the LAMOST project, the Ministry of Science and Technology of China has established a National Key Basic Research Development Program – Formation and Evolution of Galaxies. The funding level of such a national key program amounts to 20 M Chinese Yuan. The other two National key programs, Modulated Hard X-ray Telescope and Solar Activity and Space Weather, are approved and under coordination; they are considered as scientific supporting programs for mega-science projects.

4. The National Astronomical Observatories of China

Several key factors made the Chinese astronomy community feel a great need to have their National Astronomical Observatories. As a developing country, China has neither sufficient investment in astronomy, nor enough leading scientists. To realize a national mega-science project there must be a national organization which can concentrate and coordinate the best efforts from Chinese astronomers and engineers. It can only be done if NAOs maintain and fully open the key national facilities to all scientists, not only in CAS, but also in the universities

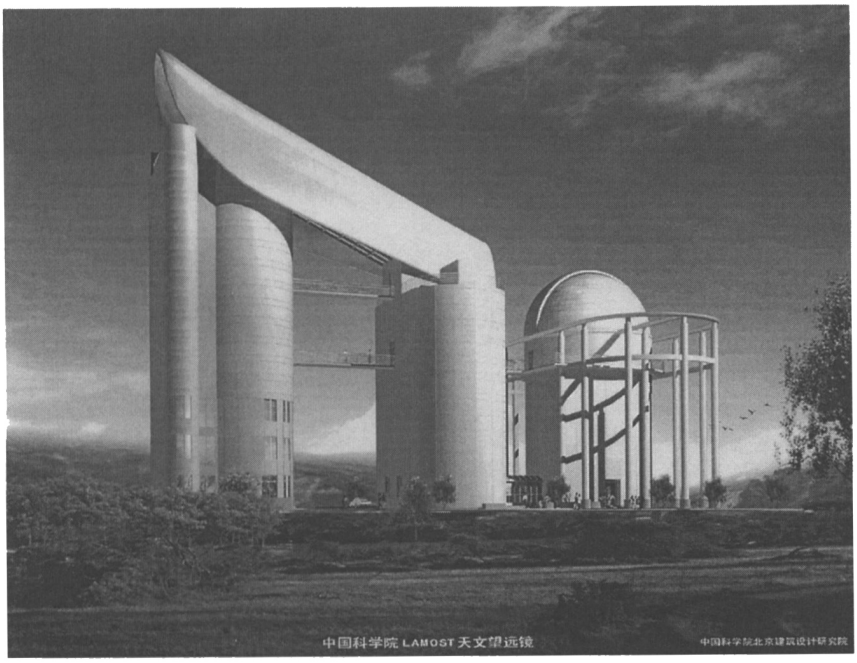

Figure 3. An artist's-eye view of LAMOST. The reflecting Schmidt plate is located in the lower dome on the right-hand side of the plot (south). The spherical primary mirror is on top of the higher tower, which is about 44 m from the ground. The central block is for the focal surface and the spectrograph room. Courtesy LAMOST team

and other institutions, to optimize scientific output. To reduce the low-level repetition in research and technical development, the NAOs can also play an important role. To have the best astronomers and engineers, and to foster leading research groups in the world, some long-term support, and an easy and comfortable working environment need to be created in NAOs.

The National Astronomical Observatories of the Chinese Academy of Sciences was established in April of 1999 on the basis of the existing astronomical observatories and stations. It consists of five observing bases (see Table 1), six common laboratories (see Section 5), 30 research groups composed into a research network, and four combined research centers, (Section 5) with some leading universities in China.

The top priority of the observing bases is to operate effectively and open fully the key national facilities (see Table 1) to domestic and overseas astronomers. At each base there are a few resident astronomers. They carry out the scientific work, in addition to supervising graduate students and astronomers who come to the observing base. Laboratories of NAOs work on keeping the existing facilities productive, at the same time, developing the new techniques necessary for future initiatives.

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Current astronomy research in China covers a diversity of areas, such as the deep survey of large-red-shift galaxies, supernovae and supernovae remnants, dark matter and gravitational lensing, galaxy interaction and star-burst galaxies, active galactic nuclei, γ-ray bursts, molecular clouds and star formation, stellar convection and pulsation, star evolution, solar magnetism and magnetic activity, astro-geodynamics, dynamics of celestial bodies and artificial bodies, astronomical optics, modern studies of ancient Chinese astronomical literature, and so on. In each working area there are some Chinese astronomers whose work has been highly regarded by international colleagues. Based on an analysis of the general trend of astronomy research in the coming new century and the status quo of astronomy research in China, nine research fields have been set up as priority for support from the NAOs. In the frontier research area, the large-scale structure of universe, formation and evolution of galaxies, high-energy and cataclysmic processes in astrophysics, formation and evolution of stars, solar magnetic activity and heliogeospace environment receive enhanced support; in applied astronomy studies (Section 5), astrogeodynamics, dynamics of celestial bodies in the solar system and artificial bodies are selected as principal fields; in technology studies, space observation and exploration, and new astronomical techniques and methods are taken as top priority.

The principal professors together with their research groups in NAOs were selected in the priority areas, by peer review and open defense. Under the direction of the principal professors, the research groups were organized. There are altogether 30 groups which were established and have received strong support from NAOs of CAS. They have become active centers of astronomy research in China, and are very attractive to young graduate students.

The NAOs look forward to the future of Chinese astronomy. To further strengthen the observation facilities, The Southern Base of NAOs is under construction in Lijiang, Yunnan Province. Currently, a 2.3-m optical telescope is under consideration, 3-m to 4-m telescopes have been identified as appropriate for this site in the future. The Chinese astronomy community continues to search for good sites for next-generation observatories. The first site survey in Tibet was made in the late 1980s. A more recent site survey in Tibet was made last June (2000) for both solar and night-time astronomy. The site-survey observations are under analysis. The observations appear encouraging. Further survey observations will be made. Figure 4 is a star-trail picture taken in Tibet at an altitude over 5,000 m.

5. Key Relations

For a developing country, it becomes most important to optimize the supporting system, and to maximize the benefits of astronomy studies to the country and the society. It is recognized that the following six relations should be properly dealt with.

1. The National Astronomical Observatories and Other Observatories.

   So far, all the Chinese observatories are national. They are institutes of CAS. The key function of NAOs is developing national facilities and having them efficiently operated and open to all active domestic astronomers

Figure 4. Site survey in Tibet in June 2000, courtesy K.X. Chang

and international colleagues; while the other observatories carry out advanced research based on the performance of the national facilities as well as their home instrumentation which is specialized for particular scientific topics. The other observatories seem more to concentrate on their own distinctive and strong points in research. All the observatories work in a complementary way to achieve the highest output of the astronomical observations. Purple Mountain Astronomical Observatory focuses on theoretical astrophysics, millimeter and sub-millimeter astronomy, and celestial dynamics; Shanghai Astronomical Observatory concentrates on the Galaxy and extra-galactic astrophysics and astrogeodynamics.

2. Observatories and Universities.

Astronomy researchers in Chinese universities have established themselves by advanced theoretical studies and comprehensive data analyses. Most of their work is in the frontier areas of astrophysics. A few current working directions are listed below for four top universities in astronomy.

- Nanjing University (NU) – γ-ray bursts and high-energy astrophysics; supernova remnants, galaxy dynamics, solar active-region physics, nonlinear celestial dynamics;
- Beijing University (BU) – pulsars, star formation;
- University of Science and Technology in China (USTC) – early universe and cosmology, large-scale structure in universe, AGN, accretion theory, solar magneto-hydrodynamics;

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- Beijing Normal University (BNU) – quasars, stellar physics.

More universities are producing high-quality research in astronomy. It has been urged that NAOs and other CAS observatories work in concert with universities to promote strongly astronomy research in China, and to improve the education of graduate students, the new generation of astronomers (Fang and Tang, 2001). To realize this, four research centers have been established in NAOs, supported both by NAOs and universities. They are Beijing Astrophysics Center in BU, East China Center of Astronomy and Astrophysics with NU, Astrophysics Center of USTC , and Astrogeodynamics Center in Shanghai with several universities and institutes. Among them, Beijing Astrophysics Center (BAC) jointly sponsored by NAOs of CAS and Beijing University was established first. It has enjoyed great success (Annual Report of BAC, 1998, 1999), and will grow up as a new astronomy department.

3. Frontier Studies and Applied Astronomy

By "applied astronomy" is meant developing and applying astronomical knowledge and methods to other disciplines in the natural sciences and to the national economy and security enterprises. For a developing country, frontier studies are fascinating and we like to see the country catch up in natural science; it helps public appreciation of science; on the other hand, applied astronomy is also important to benefit the country and people in a more direct way. The NAOs suggest a ratio of 7:3 in supporting frontier studies and applied astronomy. Currently, the applied studies are concentrated on astrogeodynamics, detection of near-Earth asteroids and comets, dynamics of the artificial bodies, solar and space-environment prediction, astronomical factors in global changes and natural disasters, modern studies of historic astronomy materials and so on. Great progress has been made in astrogeodynamics; for example, the new nutation model of a non-rigid Earth and an initial tectonic block-motion model of China have been established.

4. Scientific and Technical Work

Astronomical research depends heavily on innovations in technology and instrumentation. Therefore technical work should be considered an ingredient of astronomical investigations. The ratio of astronomers and experts in technical work is maintained at 1:1 in NAOs. Six laboratories were built in NAOs for common usage. They focus on techniques which are closely related to the key existing facilities and major projects under development, as well as on what is potentially important for future studies. Six laboratories are devoted to astronomical optics, millimeter and sub-millimeter techniques, optical and infrared detectors, VLBI technique, space-astronomy technology, and techniques for large radio-telescopes, respectively. They are distributed in Nanjing Astronomical Instrument Research Center and a few observatories.

5. Observational and Theoretical Research

   Astronomy never stops at the stage of new discoveries. Generally speaking, astronomy research includes, at least, five steps: observations, discoveries, physical understanding, mathematical descriptions, and scientific predictions. Theoretical studies are tied not only to observations and data interpretations, but often have an independent function in predicting and guiding new observations and creating new knowledge in the natural sciences more generally. To maintain a relatively independent position for theoretical astronomy is essential for astronomy research.

   Chinese astronomers have made advanced theoretical studies on stellar convection and evolution; but, generally speaking, theoretical research is a weak link in Chinese astronomy. To promote theoretical research in China more fully is of fundamental importance for Chinese astronomy in the coming new century. It has been proposed to establish a Theoretical Astrophysics Center in NAOs. Inviting scientists from theoretical physics, high-energy physics, mathematics, plasma physics and other branches of physics to work with astronomers in this center is encouraging. It is not appropriate for original theoretical research only to count papers. A small but very excellent theoretical group of astronomers is urgently needed for Chinese astronomy.

6. Competition and collaboration

   Competition always goes with collaboration in astronomy research. Astronomy is a science that demands extensive international collaboration. Chinese national observatories and universities are now open to our international colleagues. The Chinese Academy of Sciences has opened a Guest Senior Investigator Program. Under this program NAOs and all the observatories are able to provide fine working conditions and environments for their guests. Chinese astronomers are encouraged to join actively in international collaboration, observing with world-class instruments, joining in international campaigns, making collaborative data analysis and theoretical studies. This will certainly benefit Chinese astronomers by bringing them into frontier research areas. On the other hand, in such collaborations Chinese astronomers share their experiences and intelligence with the international astronomy community. The real challenge is to work on big science with only small instruments. This will raise a generation of capable astronomers. In this sense Chinese astronomers are creative. To establish a brotherly and sisterly relationship with leading astronomy groups, to join some selected international projects are essential for deeper and closer collaborations. The Asia-Pacific Space Geodynamics (APSG) Program was initiated in 1996 to coordinate research projects in plate-tectonic, crustal motion and deformation, and to study the sea level in the Asia-Pacific area, by space techniques. A Max-Planck and CAS partner-research group in astronomy was established in Shanghai Astronomical Observatory last June. Many more close collaborations are projected.

Because of the author's limited knowledge, astronomy research in Hong Kong, Aomen, and Taiwan has not been mentioned in this paper.

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Discussion

Anandaram and Kozai both asked if Chinese observatories are open to foreign astronomers. Wang replied that they are; in particular, both the Huairou and Xinglong stations of Beijing AO have been open to foreign astronomers for several years. Applications from foreign colleagues are much encouraged because of the contacts and opportunities for interaction that they give. Applications should be sent to the Principal Astronomer of the observing base concerned. Announcements of visits will be made on the home page of the National Astronomical Observatories of the Chinese Academy of Sciences:
(http://www.bao.ac.cn)