Collaboration Between SHAO (China) and NAO (Ukraine)

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Abstract: Collaboration between SHAO and NAO, which has been carried out for more than 15 years since October 1996, is reviewed. The first and second collaborative projects "Angles refinement of connection of radio and optical reference frames on the basis of CCD observations for the optical counterparts of radio sources" between SHAO and NAO was implemented during 1996—2003. A Chinese-Ukrainian network of optical telescopes for observing fast-moving objects, in particular asteroids, satellites and space debris, as well as astronomical instrumentation, software and use of rotating CCD camera in drift-scan mode were included in the agreements during 2004—2011. The latest joint project is called "Joint observation of space debris in low orbits with rotating CCD camera in drift-scan mode". The scientific results, such as a link between the optical and radio reference frames and joint observation of small space debris，are introduced. The positions of optical counterparts of ERS were determined by SHAO using telescopes in China. A catalogue of second reference stars around the ERS was compiled by NAO using observations made with the Axial Meridian Circle. Later the project was expanded into an international Joint Project between astronomical observatories from China, Turkey, Russia and Ukraine. An estimate of the link between the optical and radio reference frames has shown that the orientation angles are close to zero with an accuracy of about 5 mas. The link accuracy becomes 3 mas when the observations are combined with other studies. Two special telescopes with rotating CCD camera in drift-scan mode were constructed by SHAO and NAO for observing small space debris in low Earth orbits. Space debris objects from a coordinated list are observed with these telescopes. Orbit calculation software is being developed by both sides. After performing orbit calculation and comparing the results, a joint web site of space debris orbits will be created. The long-term collaboration between SHAO and NAO still continues today.

Key words: Astrometry; reference frames; rotating CCD camera in drift-scan mode; space debris

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1 Histories of SHAO and NAO

Shanghai Astronomical Observatory (SHAO) of the Chinese Academy of Sciences (CAS) is an amalgamation of the former Zi-Ka-Wei and Zô-Sè observatories, which were founded by the French Mission Catholique in 1872 and 1900 respectively. Before December 1950, the two observatories belonged to the Purple Mountain Observatory (PMO), and SHAO was later established in August 1962. A 40 cm double astrograph, which was the largest telescope in East Asia at that time, was installed in 1900 on the top of Zô-Sè hill. It is the one of a few telescopes in the world with which Halley's Comet was observed in both 1910 and 1986. Outstanding results, such as determination of the proper motions of RR Lyrae variable stars and some faint stars in the KZS catalogue (KZS representing the first letters of Katalog Slabykh Zvezd in Russian), were obtained. Besides, instruments such as the Danjon astrolabe, photoelectric transit and photoelectric astrolabe (type II) were also operated before 1988 for studying Earth rotation parameters, compiling star catalogues, etc.

At the end of the 1970s, new techniques such as satellite laser ranging (SLR) and very long baseline interferometer (VLBI) were developed. The first SLR station was set up at SHAO in 1975. In August 1983, a new telescope with a 60 cm aperture, which is a second-generation system, was regularly operated and attended the Monitoring of Earth-Rotation and Inter comparison of the Techniques of Observation and Analysis (MERIT) campaign. In December 1985, many improvements such as automatic tracking with computer and a high-power Nd:YAG laser with mode lock were made. It is the third-generation system of SLR with an accuracy of $\pm 5 \sim 6$ cm. In December 1991, observations at ranges up to LAser GEOdynamics Satellite (LAGEOS) in daytime were successfully carried out[1] and the accuracy had reached $\pm 2 \sim 3$ cm in May 1992. Since July 2009, a New kHz Laser with repetition rate, energy, wavelength, pulse width and divergence of 1 kHz, 2—3 mJ per shot, 532 nm, 15 ps and 0.5 mrad respectively, has been put into service. After November 1987, a 25 m radio telescope, serving as a station for the Chinese VLBI network, and a 1.56 m optical telescope have been operating regularly. Currently a new 65 m radio telescope began in operation in October 2012. To avoid light pollution, the new optical observation base is located at "Jiang-Nan-Tian-Chi" in Anji, Zhejiang Province about 175 km from the SHAO headquarter. These facilities are in frequent use today for many research projects in the fields of astrophysics, astrometry, geodynamics, etc.

There are three periods in the development history of Nikolaev Astronomical Observatory (NAO). The first period is 1821—1911. One of the oldest observatories in Eastern Europe was founded in 1821 by Admiral A. Greig as the Naval Observatory to provide the Black Sea Navy with charts, train mariners in astronomical navigation, and certify navigation equipment. Astronomical work such as compilation of star maps and catalogues, and positional determination of comets and planets then began.

During 1912—1991 NAO was one of the southern departments of the famous Pulkovo Observatory in St. Petersburg, Russia. In this period the observatory had to expand the system of the Pulkovo absolute star catalogue into the southern sky, and carried out regular observations of the Sun and the bodies in the solar system. The time service of NAO was founded in 1931 to take part in the international programs of time determination and provide high-precision time signals for astronomical observations.

Visual and photographic observations of artificial Earth satellites were carried out in 1957—1969. During 1970—1990, the observatory was an initiator and the principle organizer of several scientific expeditions with the aim of conducting observations under polar night conditions in Western Spitsbergen Island and under high-latitude conditions in the North Caucasus. Positional determinations of stars in Nikolaev were included in the international series of fundamental catalogues with high accuracy. Long-term series of observations of the solar system bodies were considered as the foundation of a new relativistic theory of planetary motion. More than thirty-five catalogues were compiled.

The third period is from 1992 to the present, in which NAO became an independent scientific organization. During the last decade, two main directions of scientific activities, namely positional determination of celestial bodies and making astronomical instrument were formed in NAO. Considerable experience has been gained in these fields. At present four CCD instruments, namely Axial Meridian Circle (AMC), Multi-Channel Telescope (modernized Zonal Astrograph), Fast Robotic Telescope (FRT) and Mobile Telescope (KT-50) are being operated regularly for observations.

2 Collaboration between SHAO and NAO

In August 1979, the seat of CAS was restored at the International Astronomical Union (IAU) during the 17th IAU General Assembly. Since then Chinese astronomers have attended various meetings organized by the IAU and exchanged scientific views with many astronomers from other countries. Many astronomers visited the Purple Mountain, Shanghai, Beijing, Yunnan and Shanxi Astronomical Observatories, as well as the departments of astronomy in some Chinese universities. Chinese astronomers also visited and worked with astronomers in other countries as visiting scholars. Agreements of collaborative research have been carried out between China and other countries.

In December 1993 Professor Pinigin, the director of NAO visited SHAO after he visited Shanxi Astronomical Observatories. During this visit, astronomers on both sides exchanged scientific views and discussed possible collaboration on “Reference System”, a topic in the frontier of astrometry. Then, the first collaborative agreement from October 1996 to December 1999 was signed by the Directors of SHAO and NAO in October 1996 after Dr. Wang Shu-he attended the International Conference “The Role of Ground-Based Astrometry in Post-Hipparcos Period” dedicated to the 175th anniversary of NAO in September. Since then the exchange of visitors has become frequently, once every two to three years.

In June 1999 Professor Jin Wen-jing and Dr. Wang Shu-he visited NAO and took part in the International Conference "Research of the Solar System Bodies by CCD Methods", and in a conference devoted to the 90th anniversary of Evgenii P. Fedorov at Kiev. During this visit, the situation of implementing the first agreement was reviewed and a second agreement (1999—2002) was suggested and prepared. It was later signed by the Directors of two Observatories. The first collaborative project "Angles refinement of connection between radio and optical reference frames on the basis of CCD observations for the optical counterparts of radio sources" was implemented during October 1996-December 2002. The positions of the optical counterparts of extragalactic radio sources (ERS) were determined by SHAO using several telescopes in China, such as the 1 m telescope at Kunming and the 2.16 m telescope at Beijing. The catalogue of the second reference stars around the ERS was complied by NAO using observations of the AMC. The papers containing the intermediate results have been published[2–4]. This project is later expanded into Russia and Turkey as it is making progress.

The agreement, updated with new contents interesting to the scientists of both countries, is signed again by the Directors every three years. In November 2003, Dr. Shulga, Vice Director of NAO, and Dr. Protsyuk visited SHAO. By this time the first collaborative project has been almost completed. The astronomers of both sides are interested at the observations of NEOs (i.e. Near-Earth-Objects such as asteroids, satellites, spacecrafts and space debris). The CCD camera in drift-scan mode is used to observe NEOs. Besides, China and Ukraine are members of the Inter-Agency Space Debris Coordination Committee (IADC), which is an international government forum for worldwide coordination of activities related to the issues of man-made and natural debris in space. They are responsible for collecting and distributing data on space debris. In order to precisely determine the orbits of NEOs and monitor them, an observing network is necessary and a test was carried out. The third agreement of collaborative project ("Manufacture, Installation and Application of CCD Camera in Drift-Scan Mode") was implemented from January 2003 through December 2005.

During November 21—30, 2005, Prof. Pinigin and Dr. Shulga were invited to visit SHAO and a new agreement (2006—2008), which covered some new research fields, was signed by the Directors of SHAO and NAO on November 30, 2005.

In order to search for NEOs in all directions of the sky, the rotating CCD camera in drift-scan mode should be used. The first discussion on this topic was carried out on September 19—28, 2006, when Drs. Tang Zheng-hong and Yu Yong of SHAO were invited to visit NAO and took part in the international conference "Enlargement of collaboration in ground-based astronomical research in SEE (South East Europe) countries: Studies of the near-Earth and small bodies of the solar system". Later when Drs. Shulga and Sybiryakova, a young scientist from NAO, were invited to visit SHAO during November 8—22, 2008, the collaborative project on “Joint observation of space debris with rotating CCD camera in drift-scan mode” (i.e. the fifth collaborative agreement from January 1, 2009 through December 31, 2011) was discussed and signed by the two Directors. The latest one, i.e. the sixth collaborative agreement (2012—2014), is being implemented at the moment.

According to these agreements of exchanging visitors during 1996—2010, Drs. Mao Yin-dun, Li Yan etc. from SHAO and Drs. Kovalchuk and Kozyryev from NAO visited and worked at the collaborative observatories, NAO and SHAO, respectively.

3 Scientific Results from Collaboration

(1) Link Between Optical and Radio Reference Frames

In a joint project between astronomical observatories from China, Turkey, Russia and Ukraine, a total of about 300 optical counterparts of the International Celestial Reference Frame (ICRF) radio sources were observed mostly during 2000—2003. Observations were carried out with two telescopes equipped with CCD cameras: the Russian-Turkish Telescope with aperture 1.5 m (RTT150), the fully automated Cassegrain telescope located at the TÜBİTAK National Observatory (Turkish: TÜBİTAK Ulusal Gozlemevi, TUG), Turkey, and the 1 m telescope located at Yunnan Astronomical Observatory (YNAO), China. The details are listed in Table 1. In addition, there are 8 fields around ERS obtained on the RTT150 with a CCD (AP-47p) of size 1024 × 1024 pixels and 6 fields around ERS obtained on the 2.16 m telescope of the National (Beijing) Astronomical Observatory with a CCD of size 2048 × 2048 pixels. The field of view (FoV) corresponding to both of CCD are $4' \times 4'$ and $10.5' \times 10.5'$ respectively.

Table 1　Telescopes and CCD Cameras

Telescope	RTT150，TUG	1.0 m, YNAO
Location	Antalya, Turkey	Kunming, China
Coordinate (λ, φ)	$+30°20'$, $+30°49'$	$+102°20'$, $+25°02'$
Height	2500 m	1000 m
D/F^*	1500 mm/11 600 mm	1000 mm/13 000 mm
CCD	ST8, AndorDW436	TI
Number of Pixels	1530 × 1020, 2048 × 2048	1024 × 1024
Pixel Size	9 μm × 9 μm, 13.5 μm × 13.5 μm	24 μm × 24 μm
Pixel Scale	0.16″/pixel, 0.24″/pixel	0.37″/pixel
FoV	$4.1' \times 2.7'$, $8.2' \times 8.2'$	$6.5' \times 6.5'$

* D and F indicate aperture and focal length of the telescope.

One of the main problems in astrometric reductions in these small fields is the absence of reference catalogues with precise positions and proper motions. In small CCD fields, one cannot use well-known catalogues with low star densities such as Hipparcos, Tycho, or Tycho2. The first reduction of our observational data was made with the United States Naval Observatory (USNO) catalogues (version USNO A2.0 and USNO B1.0) as reference catalogues. The results of the reduction with reference stars from the USNO B1.0 catalogue show large systematic errors of about 200 mas in declination. Due to their low precisions, the optical stellar positions from these catalogues cannot be used to refine the link parameters between the radio and optical systems. USNO CCD Astrograph Catalog version 2 (UCAC2) and Two Micron All-Sky Survey (2MASS) are more accurate catalogues, which have made it possible to partly re-process the available observational data. But it should be noted that UCAC2 does not have high enough star densities for use as a reference catalogue in small CCD fields; furthermore, the distribution is not over the whole celestial sphere, but only up to 48° (somewhere −52°) in northern declination. On the other hand, the 2MASS catalogue has no proper motions. But the mean epochs of 2MASS and our optical observations are very close to 2000. This is why 2MASS is used here as a reference catalogue for precise reduction of optical positions.

Finally, the optical positions of the 126 ERS in the declination zone $-30° \leqslant \delta \leqslant 50°$ were measured with respect to UCAC2 as a reference catalogue, and those of 171 ERS in the declination zone $-40° \leqslant \delta \leqslant 80°$ were measured with respect to 2MASS. The mean accuracies of the measured positions are 38 mas in right ascension (RA) and 35 mas in declination (DEL). A comparison $(O-R)$ between the measured optical positions referred to the reference stars from UCAC2 and 2MASS and the radio positions from the current ICRF list are given in Table 2. The estimation of the link parameter values between the optical and radio reference frames has shown that orientation angles are near zero with an accuracy of about 5 mas. The link accuracy becomes 3 mas when the observations are combined with other studies[5].

Table 2 Comparison Between the Measured Optical Positions of Reference Stars from UCAC2 and 2MASS and the Radio Positions from the Current ICRF List

Reference Catalogue	$(O-R)$ in RA, mas in mean	$(O-R)$ in DEC, mas in mean	N^*
UCAC2	-4 ± 5	15 ± 4	130
2MASS	9 ± 6	27 ± 6	182

* N means the number of $(O-R)$ differences referred to each catalogue.

(2) CCD Camera in Drift-scan Mode

In July and August 2006, observations of a Geostationary Orbit (GEO) satellite were tested at SHAO using a 20 cm Maksutov telescope with a CCD of size 1160×1040 pixels in stare mode and drift scan mode. Not only the good circular images of the reference stars and GEO satellite but also the positional coordinates of objects with high precisions were obtained. The total internal errors of optical positions are $0.2'' \sim 0.4''$[6].

(3) Optical Observations with the Ukrainian-Chinese Network

This project is directed towards the creation of the first Ukrainian-Chinese network of optical telescopes for observing satellites and space debris in low orbits (less than 2500 km). The telescopes are equipped with short focus objectives and sensitive Watec CCD cameras in TV mode. A list of the telescopes is given in Table 3, in which the abbreviation words of RI NAO, RI AOONU, AOLNU and LSRUNU indicate Research Institute "Nikolaev Astronomical Observatory", Research Institute "Astronomical Observatory of Odessa National University", Astronomical Observatory of Ivan Franko of Lviv National University and Laboratory for Space Research of Uzhgorod National University[7]. Now all telescopes with aperture of 85 mm and Watec CCD cameras are used in this observing network.

Table 3 The Ukrainian-Chinese Network

Institute	Telescope	Aperture(mm)	Focal Ratio	FoV
RI NAO	FRT	85	1.8	$4.2^\circ \times 3.2^\circ$
RI AOONU	KT-50	250	2.5	$1.5^\circ \times 1.1^\circ$
AOLNU	TPL1M	250	2.5	$1.5^\circ \times 1.1^\circ$
LSRUNU	TPL1M	85	1.5	$4.2^\circ \times 3.2^\circ$
SHAO		85	1.8	$4.2^\circ \times 3.2^\circ$

Orbit modeling of the artificial Earth satellites taken from the USSTRATCOM (United States Strategic Command) catalogue in the observation zone of the network has shown that up to 1000 ~ 10 500 objects can be tracked with a data update period of not more than 10 days. It has forecast accuracy not worse than those of the USSTRATCOM catalogue. Observations have shown that we could use the equipment to observe objects with reflective areas of 0.1 m^2 and masses of 50 kg.

During the first observation campaign held in 2009, measurements were carried out using two methods: TV and stare modes, along all visible orbital arcs in a limited sky zone with the largest density of objects. The first method is aimed at obtaining maximum data volume to estimate with the highest possible accuracy of orbit determination. The second method is designed to estimate with a possibility of catalogue maintenance and enlargement for observations with several static telescopes. The estimated quality of the measurements by each method for orbit improvement and forecast accuracy are calculated[7].

(4) Rotating CCD Camera in Drift-scan Mode

A normal CCD drift-scan system is often used to survey the sky and get images of stars in the time-delay and integrate (TDI) mode at the apparent sidereal rate. With a CCD camera in drift-scan mode, stars can still be tracked even when the telescope remains in idle state. The orbits of middle and low-orbit space debris are in different directions. To observe these objects with a long exposure, a CCD camera in drift-scan mode needs to be rotated to make the direction of a pixel line parallel to the orbit of the object which also has bad predictions. Since the drift-scan mode can track objects for some time, small telescopes with rotating CCD cameras in drift-scan mode can catch small and faint space debris. The first test using a prototype telescope (D = 10 cm, F = 50 cm, $FoV = 4° \times 4°$) mounted on a 1.56 m telescope with a CCD camera (Apogee U9000) in rotating drift-scan mode was implemented in October 2007, and some preliminary results of observing COSMOS 2289, COSMOS 2275 and LEO 14521 at altitudes of 19 000, 19 000 and 1526 km respectively are given. It is shown that a 10 cm×10 cm space debris could be observed using a telescope with D = 400 mm and F = 600 mm, and equipped with an Alta U9000 CCD[8].

In order to conduct observations regularly, two sets of telescopes with a rotating CCD camera (Alta U9000) were fabricated. The optical parameters of the SHAO telescope and its CCD camera are listed in Table 4. Here FWHM, AZ, EL, SNR indicate full width at half-maximum, azimuth, elevation and signal to noise ratio.

Table 4 Parameters of the SHAO Telescope and Rotating CCD Camera

Optical Parameters of the Telescope		Parameters of the CCD Camera	
Parameter	Value	Parameter	Value
Aperture	300 mm	Chip	Kodak KAF-09000
Focal Length	250 mm	Number of Pixels	3056 × 3056
Plate Scale	825.1″/mm	Pixel Size	12 μm × 12 μm
FoV	8.35° × 8.35°	Pixel Scale (Binning= 2)	20″
FWHM	30″	Dark Current	$0.3e^-$ /pixel/s
Point Accuracy	10′	Operating Temperature	−20°C
Moving Speed in AZ	14.4°/s	Photosensitive Area	36.7 mm×36.7 mm
Moving Speed in EL	10.4°/s	Limiting Magnitude	11.2 mag
Rotating Speed	3.14°/s	(for 1 second exposure time)	(SNR = 5.7)

By 2011, several small space debris have been observed by this telescope, including one with Radar Cross Section (RCS) about 0.028 cm^2 at distance more than 3000 km.

4 Future Prospects for Collaboration

The collaboration between SHAO and NAO has a history of more than 15 years, which have yielded numerous scientific results as described above. In particular, the project of joint observation of small space debris in low Earth orbits involved a wide range of activities (including instrumental design, observing software development, and building a rotating CCD camera in drift-scan mode) that takes only 3 years (2009—2011) to finish. Close collaboration and superior quality of the participants from both sides have played an important role in completing the tasks rapidly. It is well known that both observatories have rather long histories of research and development in astrometry. Considering their duties at the Ministry of Science and Technology of the China and the State Agency on Science, Innovation and Information of the Ministry for Education and Science of Ukraine, as well as the currently available operating instruments, we suggest the following projects for future cooperation:

(1) After the first campaign with the Chinese-Ukrainian network of optical telescopes for the observation of space debris in low orbits, these observations will be carried out regularly. Professor Zhu Neng-hong, Drs. Zhang Zhong-ping and Tang Zheng-hong of SHAO discussed in more detail about the construction of optical telescopes network with Ukrainian astronomers from the Nikolaev, Odessa, Lviv and Uzhgorod Astronomical Observatories on May 22—26, 2010, after the International Workshop "Methods and Instruments in Astronomy: From Galileo Telescopes to Space Projects" held at NAO on May 18—21, 2010. Following the previous collaborative work and the meeting minutes of "Construction of Chinese-Ukrainian Space Monitoring Network", the network will be extended to larger telescopes and will be able to monitor small space debris to obtain their positions and photometry jointly.

(2) SHAO and NAO are members of the IAU working group "Astrometry by Small Ground-Based Telescopes" in Division I (Fundamental Astronomy), which was initiated during the XXVIth General Assembly of the IAU in Prague in August 2006, and extended for a new triennium at the XXVIIth IAU General Assembly held in Rio de Janeiro in August 2009. Both observatories are also members of the working group "Gaia Follow-Up Network for Solar System Objects (Gaia-FUN-SSO)" in the Coordination Unit 4 of the Gaia Data Processing and Analysis Consortium (DPAC), which is one of the three ground-based networks spread out in longitudes and latitudes for Gaia. There are two distinct objectives for the collaboration: (a) The observation of Solar System Objects (SSO) by the space astrometry mission Gaia will be constrained by a scanning law. Several detections of interesting objects may be done with no possibility of further observations by the probe. These objects will then require complementary ground-based observations. It will provide orbits to avoid loss of newly discovered objects by Gaia based on short time-scale observations; (b) It will allow better characterization of new objects and selected targets (e.g. asteroids, possibly comets, planetary satellites), such as the determination of asteroid mass or the Yarkovsky effect based on astrometric and photometric observations on a longer time scale. In particular, observations of the Gaia satellite itself can be performed to obtain the orbitography of the observing platform to the precision required by the DPAC data-reduction pipeline.

(3) Both observatories have studied astrometry for a long time. Some projects, such as extension

of the observations to the South declination zone and to faint stars (17~19 mag) for determination of the Solar apex, discovering the companion star of binary or multiple stars, determination of proper motion in Guide Star Catalog II (GSCII) with high precision etc., are interesting to astrometists[10] on both sides.

(4) Both observatories have long histories of photographic astrometry[11]. Many photographic plates have been accumulated. The working group on Preservation and Digitization of Photographic Plates (PDPP) in the IAU Commission 5 was initiated in 2000 and has been maintained up till now. SHAO is the center of preserving and digitizing photographic plates in China. About 30 000 plates have been preserved in a semi-basement under the observing room of the 40 cm refractor at the Zô-Sè section with air condition and humidity controlled[12].

This work will be divided two steps. One is complication of the plate archive with unified format, and the resulting materials will be entered into the International Wide Field (> 1°) Photographic Database (WFPDB) at the Institute of Astronomy of the Bulgarian Academy of Sciences in Sofia, Bulgaria. Another work is plate digitization that will be tested with a commercial scanner. A large number of plates will be digitized step by step, but the plates along the ecliptic zone and those including interesting targets will be measured first. After plate digitization the materials will be released to the Virtual Observatory[13,14]. Some projects will be carried out with these materials and current measurements obtained through collaboration.

Due to the notable achievements made in the cooperation between SHAO and NAO for more than 15 years, the collaboration will be expanded into other observations in China and Ukraine. The following topics will be under further consideration:

(1) SLR Network

From the end of the 1980s to the end of the 1990s, the Chinese SLR network that includes Shanghai, Wuhan, Changchun[15], Beijing, Kunming[16], Xian and one mobile station was established, while the network of Ukraine includes the Golosiiv-Kiev, Lviv, Simeiz and Katzively stations. These stations are being operated regularly and are participating in the International Laser Ranging Service (ILRS). Observation data can be used to improve the orbital parameters; such computation could still be performed properly with less data collected from fewer observations when weather conditions are bad, since these observatories are widely distributed in longitudes and latitudes.

(2) VLBI

The Chinese VLBI network has sites in Shanghai (25 m), Beijing (50 m), Urumqi (25 m) and Kunming (40 m), plus an additional mobile station (3 m). But the mobile one is not often used now. The largest radio telescope with a 65 m aperture at SHAO has been operating since October 2012. There are some radio telescopes in Ukraine, such as the RT-70, one of three 70 m radio telescopes and planetary radars set up by the former Soviet, at the Center for Deep Space Communications in

Yevpatoria (sometimes romanized as Evpatoria), Crimea. If all these stations, expanding spatially in longitudes and latitudes (especially in longitude), join together, it would be very useful for deep space exploration and determination of the orbits of spacecrafts, space debris and asteroids, as well as for research in astronomical radio science.

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上海天文台与尼古拉耶夫天文台之间的合作

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摘　要： 回顾了从1996年10月起上海天文台与尼古拉耶夫天文台15年多的合作历程。1996—2003年上海天文台与尼古拉耶夫天文台第一和第二次合作课题是“从射电源光学对应体的CCD观测进一步研究射电和光学参考架的联系”，2004—2011年两台的合作协议包括用中国–乌克兰光学望远镜网观测快速运动的天体，特别是小行星、卫星和空间碎片，以及天文仪器研制、软件和旋转漂移扫描技术的应用等。最近的联合项目是“用CCD旋转漂移扫描照相机联合观测低轨的空间碎片”。本文简述了合作的科学成果，如光学和射电参考架的联系和联合观测小的空间碎片，上海天文台用中国的望远镜测定射电源光学对应体的位置，尼古拉耶夫天文台用轴向子午环编制射电源光学对应体附近的二级参考星星表。之后，此项目扩充为国际合作项目，参加国家有中国、土耳其、俄罗斯和乌克兰。射电和光学参考架联系的计算值表示指向角为零，精度为5 mas。如果加入其他观测，则精度为3 mas。为了观测低轨小的空间碎片，上海天文台和尼古拉耶夫天文台分别研制了带有CCD旋转漂移扫描照相机的望远镜。根据空间碎片的位置列表，已用这两台望远镜观测到一些碎片。双方正在编写空间碎片的轨道计算软件。在对两个轨道计算结果比较后，将建立一个空间碎片的联合网站。当前上海天文台与尼古拉耶夫天文台的合作正在继续进行中。

关　键　词： 天体测量；参考架；漂移扫描模式的旋转CCD照相机；空间碎片