PoS PROCEEDINGS OF SCIENCE

Long March to the SKA

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Abstract: The SKA (Square Kilometre Array) project was proposed by astronomers from 10 countries, and first coordinated by the LTWG (Large Telescope Working Group) formed at the General Assembly of URSI (International Union of Radio Science) in 1993. I will review the Chinese participation in the SKA project at national, regional and global levels in the past two decades. During such a Long March to the SKA, a number of national Megascience projects have taken root and have been (are being) successfully constructed, with costs at the 100 M US dollar level. They include the LOFAR (Low Frequency ARray), FAST (Five-hundred meter Aperture Spherical Telescope), ASKAP (Australia SKA Pathfinder) and MeerKAT (South Africa SKA Pathfinder). The FAST project can be seen as a forerunner of the KARST (Kilometre Area Radio Synthesis Telescope) project, which was one of the two LDSN (Large Diameter Small Number) concepts for realizing the SKA. A close look at the FAST site gives an impressive snapshot of the construction phase in China. The Long March to the SKA continues, while the SKA enters the pre-construction phase (2012-2015), towards the 10% SKA construction (2016-2019) called SKA1 and the rest of SKA (2019-2023) called SKA 2, under the leadership of the SKA Organisation (SKAO) established on November 23, 2011.

Resolving the Sky - Radio Interferometry: Past, Present and Future
Manchester, UK
April 17-20, 201

[1] Speaker

1. Introduction

In the early 1990s, a few individual astronomers dreamed of having a very large radio telescope (LT, now called SKA) to explore the early Universe by studying neutral hydrogen. In 1993, astronomers from 10 countries proposed to build the next generation telescope array with a collecting area of one square kilometer, distributed over 300 km, covering the frequency range of 200 MHz to 2 GHz. In the mean time, the LTWG was established at the URSI GA in Japan, to develop the scientific goals and technical specifications for a next generation radio observatory. Since then, a number of milestones were established for the SKA.

Firstly, five engineering concepts were proposed to realize the SKA, including the Chinese KARST to build about 30 big dishes of Arecibo-like radio telescopes, by making use of karst depression-like sinkholes as telescope sites in China. The Canadian LAR (Large Adaptive Reflector), US ATA (Alan Telescope Array), Dutch AA (Aperture Array), and Australian Luneberg Lens (LL), etc., were summarized in the newspaper at the IAU GA in Manchester in 2000 (Fig. 1), when the LTWG was succeeded by the ISSC (International SKA Steering Committee) to coordinate the global SKA R&D at astronomical institute (observatory) level.

Astronomers Sign International Agreement to Plan Square Kilometre Array

Options for the stations of the SKA, from the top: A set of large (>300m) spherical reflectors; A large (>200m) reflector with the receiver supported by an aerostat; An array of small (<10m) parabolic dishes; A fixed planar (electronically phased) array; An array of spherical (>10m) refracting lenses.

Leading astronomers from Europe, North America, Asia and Australia will today sign an agreement jointly to plan a huge new radio telescope, the Square Kilometre Array (SKA), which will come into operation in the middle of the next decade. The General Assembly is an ideal opportunity to inaugurate the next stage of development of this truly global project.

The signing ceremony will take place at 17:30hrs in the Bragg Lecture Theatre in the Schuster Building at the end of the joint session on 'Future Observational Multi-Wavelength capabilities in Astrophysics', organized by the Working Group on Future Large Scale Facilities (WGFLSF) and IAU Division XI (Space and High Energy Astrophysics). The last part of the programme is a round-table discussion about the process of international co-operation and coordination.

Radio astronomers regard the SKA as a paradigm for the organization of future global astronomy projects. The SKA was the first radio astronomy project to have been 'born global' following the guidelines for successful international collaboration discussed at the 1994 IAU General Assembly in The Hague. The current concept has grown out of discussions over the past six years within the URSI/IAU Large Telescope Working Group and the OECD Global Science Forum. An International SKA Steering Committee (ISSC) has now been constituted to promote and to oversee the planning of the project. The signing of a formal Memorandum of Understanding will establish the ISSC for a period of five years. The signatories will be:

Prof. Ron Ekers: Australian SKA consortium
Dr. Don Morton: Herzberg Institute of Astrophysics, Canada
Prof. Ai Guoxiang: National Astronomical Observatory, PR China
Prof. Rajaram Nityananda: National Centre for Radioastrophysics, TIFR, India
Prof. Harvey Butcher: European SKA Consortium
Dr. Jill Tarter: United States SKA Consortium

At present 24 leading institutions in ten countries have agreed to pool their research and development efforts, with each individual institution concentrating on only a part of the overall design. Their shared aim is to reach agreement on the fundamental design of the SKA by 2005 and to begin construction in 2010.

In order to achieve its ambitious astronomical goals, the design of the SKA will integrate computing hardware and software on a massive scale in a revolutionary break from current radio telescope designs. The SKA is a challenging project, and as Ron Ekers of the Australia Telescope National Facility says:

"Designing, let alone building, such an enormous technologically-advanced instrument is beyond the scope of individual nations, or even small groups of nations. The SKA is therefore being planned from the outset as a truly-global telescope project."

The SKA will be a uniquely sensitive instrument. Its collecting area will be 50 to 100 times larger than today's biggest radio imaging telescopes, the VLA and the GMRT, and 200 times larger than the pioneering Lovell Telescope at Manchester University's Jodrell Bank Observatory (which can be visited during the General Assembly).

The idea of the SKA sprang from radio astronomers' desire to detect the faint 21-cm emission from atomic hydrogen in structures formed soon after the Big Bang, and in the galaxies which developed from these structures. As ISSC member Peter Wilkinson (University of Manchester) says:

"One square kilometre is not just a convenient round number—it arises naturally from a desire to image the hydrogen gas in distant galaxies with 0.1 arcsecond resolution".

Radio astronomy has been crucial in discovering phenomena such as quasars, pulsars, gravitational lenses, superluminal motion and the cosmic microwave background. It has led to three of the five Nobel prizes awarded for work in astrophysics, including all those awarded for observational work. Major advances in knowledge can be expected from a new radio telescope with the sensitivity of the SKA.

Radio telescopes have a big advantage over those operating at most other wavelengths, because they can see through cosmic dust. This dust often prevents optical telescopes seeing into star-forming regions and the centres of galaxies. The latest sub-millimetre results from SCUBA on the James Clerk Maxwell Telescope show that dust can even obscure entire galaxies at visible wavelengths. Radio telescopes have another advantage in that they can be combined in arrays to produce images with the highest resolution in all branches of astronomy. On completion the SKA will, therefore, be the world's premier instrument for astronomical imaging.

The SKA's superb resolving power- which could extend to one milliarcsecond- and exceptional image quality will also provide crucial new information on the formation and early history of stars, galaxies and quasars unaffected by obscuring dust. Its enormously high sensitivity will mean that, for the first time, objects in the early Universe can be studied in detail in the radio range. The SKA is thus the perfect scientific complement to the large optical (e.g. CELT, ELT, OWL), infrared (NGST) and millimetre wave (ALMA) telescopes currently being planned.

A 6-page explanatory brochure about the SKA, written by the ISSC, has been widely distributed during the General Assembly. The full current science case for the SKA, and an electronic version of the brochure can be obtained from the SKA Web site at http://www.ras.ucalgary.ca/SKA

Peter N. Wilkinson
University of Manchester
Jodrell Bank Observatory

Members of the SKA ISSC at last week's SKA Technical Workshop held at Jodrell Bank Observatory.

New People

Two more Joint Discussions take place today

Fig. 1 The newspaper announced the establishment of the ISSC in Manchester, with a list of engineering concepts for realizing the SKA in 2000

Secondly, while the SKA project drew more attention of the world, the SKA Science was further developed to a broader range of subjects with key science identified (Carilli & Rawlings 2004), i.e., cradle of life, strong field tests of gravity, etc. The SKA technical specifications evolved to higher frequencies (10 GHz, and up to 25 GHz) and higher resolutions (> 3000 km baseline) where the unique capabilities of the SKA can be exploited. The LNSD (Large Number Small Diameter) class concept, like the ATA, AA and LL, was adopted as the reference design for the SKA with advantages of higher survey speed over the sky than that of the LDSN ones, including the KARST and LAR concepts. The four SKA sites were shortlisted to two, i.e., Australia together with New Zealand, South Africa together with other 8 neighbouring or nearby African countries, although China was ranked at the top for its measured RFI (Radio Frequency Interference) enviroment, but low from the point of view of the long term RFI situation. The ISSC was succeeded by the SSEC (SKA Science and Engineering Committee) with 21 members in 2008, to act as the primary forum for interactions and decisions on scientific and technical matters for the SKA, coordinated by the SPDO (SKA Program Development Office) from the expanded ISPO (International SKA Project Office, established in 2005), with common funding from member countries. Richard Schilizzi was appointed as the first and only ISPO and then SPDO Director to play a leading role in the Science and Technology R&D for the SKA.

Thirdly, funding agencies from SKA participating countries became involved, working together with the SSEC to co-lead the SKA activities. Construction of SKA pathfinders and precursors was started, and the site bidding was beginning serious investigation of key site characteristics. The SKA Funding Board was formed in Rome with signatures from nine nations on April 2, 2011: Australia, China, France, Germany, Italy, the Netherlands, New Zealand, South Africa and the UK, to prepare for the establishment of a SKA legal entity. On November 23, 2011, seven nations including Australia, China, Italy, the Netherlands, New Zealand, South Africa and the UK, signed the Membership Agreement to fund a SKA Organisation, to formalise relationships between the international partners and centralise the leadership of the project, led by the Board of Directors, moving into a resourced SKA era, the SKA pre-construction phase for the period 2012 to 2015. Later on, Canada signed on as a new full member on March 19, 2011, Sweden signed on as the 9th full member of the SKAO on June 27, 2011. India became the first associate member on April 4, 2011, and is preparing to become a SKA full member in 6 months.

2. Chinese participation in the SKA

China was one of the 10 initial countries co-proposing the LT (renamed SKA after 1999), joining the LTWG at the URSI General Assembly in 1993. As the representative body from China, the National Astronomical Observatories of the Chinese Academy of Sciencese (CAS), NAOC (the former Beijing Astronomical Observatory), working together with about 15 universities and institutes in China as a SKA Consortium, proposed and developed an engineering concept in 1994 to realize the SKA, called KARST, aiming to build the SKA with about 30 Arecibo-type big dishes, by making use of the extensive existing limestone landform, karst depressions in Guizhou province, located in southwest China.

2.1 Domestic SKA activities

Since 1994, the SKA Consortium in China, led by the NAOC, started the long march to the SKA site survey. Together with the Institute of Remote Sensing Applications of the CAS, they found about 400 karst depressions among some 1000 sinkhole-like landforms, being suitable to host the Arecibo-type telescopes, each more than 200 m in diameter. Being a technical result of the global SKA activities, the world's largest single dish FAST, as a prototype for the KARST, was born in 1997, and further funded in 2007 by the NDRC (National Development and Reform Committee，China) with a budget of about 100 M US dollars. Its planned 5.5 year construction began in March, 2011.

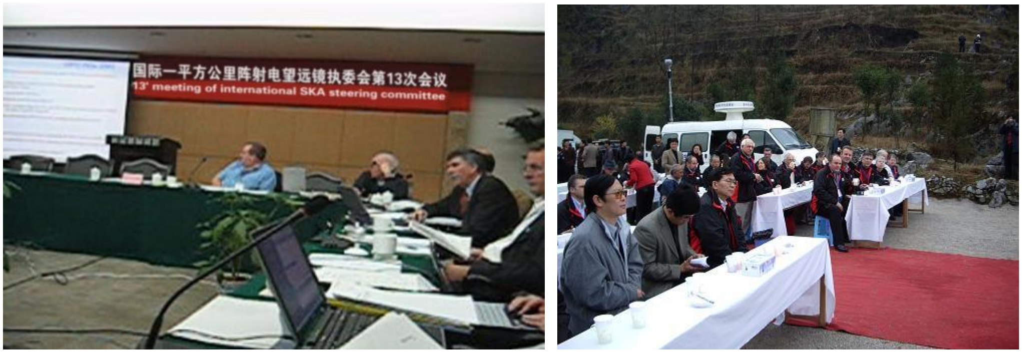

Fig. 2 In 2005 the ISSC-13 took place in the Guizhou hotel (left panel); the participants visited the potential SKA site in Anshun city (right panel).

The third meeting of the LTWG and a workshop on large spherical radio telescopes was held in the Huaxi hotel of Guiyang city in October 1995, with a long trip (~7 hr drive for about a 200 km long rough road) to explore the karst depressions. The proceedings of the LTWG-3 and of the Workshop detail the results. Five years later, IAU colloquium182 was held in the Guizhou hotel in April 2000, addressing Sources and Scintillations as part of the SKA Science case; the proceedings of IAU Colloquium 182 was published by Kluwer Academic Publishers. Another 5 years later, the 13th ISSC meeting was held at Shengfeng hotel of Guiyang city in 2005 (Fig. 2, left panel), with a long trip (~4 hr on a 130 km unpaved road) to investigate potential SKA sites (Fig. 3, right panel). Again, 5 years later, the domestic conference of Chinese Radio Astronomy and Technology, namely CRAT2010, the first joint conference hosted by three academic bodies, including the Radio Astronomy Committee of the Chinese Astronomical Society, the Radio Astronomy Branch of Chinese Radio Science, and the Radio Astronomy Key Laboratory of CAS, was held in Guizhou University to broadly advertise SKA.

Fig. 3 The first RFI measurements taken at karst landforms in 1994 (left panel); the calibration team worked at the potential SKA core site, Dawodang depression, in 2005 (right panel).

The radio environment at the potential SKA sites was measured first with portable RFI equipment (Fig. 3, left panel), borrowed from ASTRON (formerly NFRA), the Netherlands, in fall 1994. We continued to investigate distance effects between the potential site and towns and/or big cities, up to long sampling and monitoring over a decade, in a frequency range from 70 MHz – 22 GHz. These were carried out together with local support from the Guizhou Radio Monitor Station, further calibrated by the international SKA RFI team (ASTRON staff) for about 6 weeks, during July – August in 2005 (Fig. 3, right panel). China then submitted a 《Proposal for Siting the SKA in China》 at the end of 2005, and a《SKA Site Spectrum Monitoring Data Summary》 by the end of March 2006, as one of the four site candidates: Argentina, Australia together with New Zealand, China and Southern Africa. A Chinese team was sent to Cambridge in the summer of 2006 to defend its SKA site proposals. The SKA site shortlist was made in the fall of 2006 by international reviewers as had been scheduled by the SKA roadmap.

Since China did not make the shortlist in the site competition game, the NAOC has been working hard on the FAST R&D, and achieved approval of its funding proposal for constructing the FAST as a national MegaScience project in 2007.

On the other hand, industrial engagement in the SKA opened a new avenue for China to continue its role in the global SKA project. Considering the CETC54's successful bid to build the ASKAP antennae, NAOC and CETC54 established a joint research body in January 2010 after half a year's investigaton, JLRAT (Joint Laboratory for Radio Astronomy Technology), in order to find more active ways to contribute to the SKA project, to explore a new mode to establish and develop a radio astronomy technology laboratory, and to train a new generation of radio astronomical engineers by making use of existing resources in both institutions. One of the big achievements of the JLRAT has been to coordinate the SKA dish R&D closely with the SPDO. For example, there was a special session of half a day dedicated to the new proposal of the DVAC (Fig.4) during the LOFAR inauguration in the Netherlands in the summer of 2010.

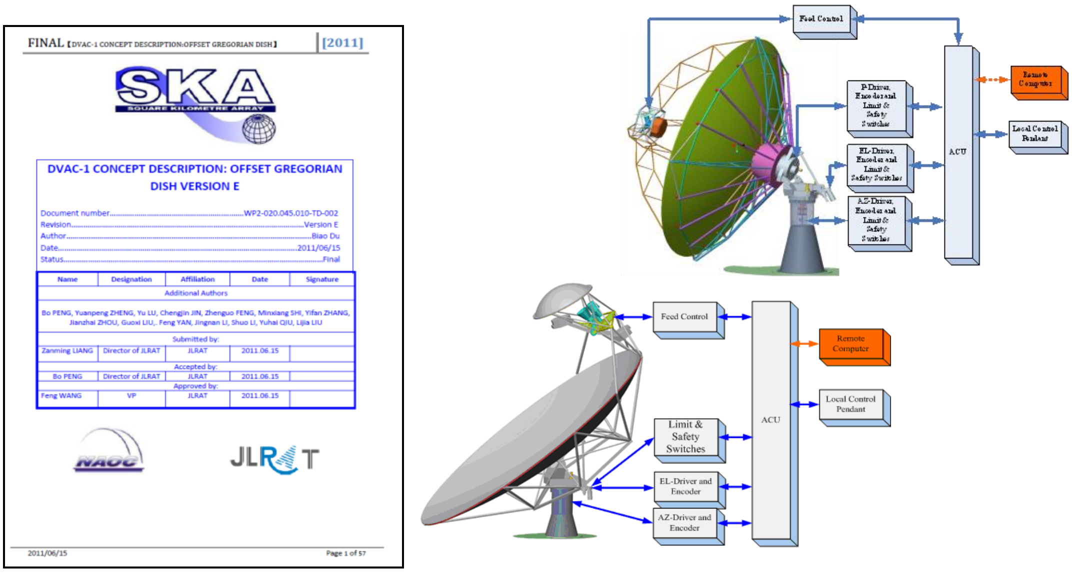

Fig. 4 Documents of the proposed DVAC (Dish Verification Antenna, China), and the concept drawings of DVAC-1 (Offset Gregorian) and DVAC-2 (Prime Focus) in 2011

There have been huge efforts to get China engaged in the SKA pre-construction phase. For example, the NAOC organized a review panel meeting on June 17 2011, addressing the feasibility of China's continuing in the SKA project for the period 2012-2015, i.e., the SKA pre-construction phase, within the Chinese astronomical community. Four months later, the MOST (Ministry of Science and technology, China) called a review panel meeting on October 28, 2011, addressing China's participation in international large astronomical facilities, including the SKA and TMT (Thirty Meter Telescope), within the related Science and Technology community all over the China. China's participation in the SKA, especially the SKA pre-construction phase, gained much support from both expert panels mentioned above. China continues the long march to the SKA, after its ~ 20 year engagement as co-initiator and co-founder of the SKA project.

Fig. 5 Korea, Japan and China met in South Africa together with standing SSEC chair in 2009 (left panel), and the first Workshop on East Asian Collaboration on SKA in Daejeon 2011 (right panel)

2.2 Regional SKA activities

The interest of East Asian countries and regions in SKA has been growning, and China plays a major role. For example, Korea, Japan and China met on a trip in Feb. 2009 to explore the potential SKA core sites in South Africa, and discussed setting up an East Asian SKA Consortium (Fig. 5, left panel). Later on, there were several telecons (Skype) between China, Japan, Korea and Taiwan on SKA activity updates and East Asia SKA Consortium business. Most recently there was a conference held in Daejeon, Korea, called a Workshop on East Asian Collaboration on SKA, in December 2011 (Fig, 5, right panel). Among the results, Korea may become a full member of SKAO after China in East Asia.

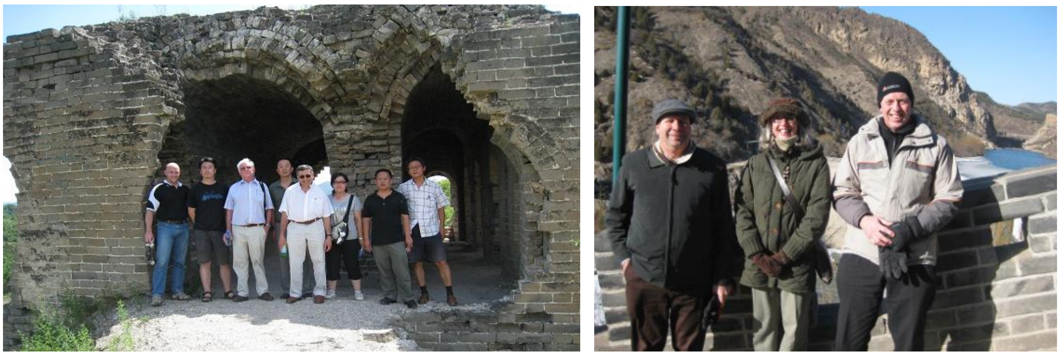

Fig. 6 MeerKAT degation climbed Gubeikou Great Wall in July 2009 (left panel); SPDO, ASKAP and TDP delegation climbed Jinshanling Great Wall in January 2010 (right panel).

2.3 Global SKA activities

There have been many interactive SKA activities between China and other international partners. For example, there was a MeerKAT delegation in July 2009 (Fig. 6, left panle), SPDO, ASKAP and TDP (Technology Development Program in US) delegations to China in January 2010 (Fig. 6, right panel). There was a telecon held between SPDO, CSIRO and JLRAT on dish CoDR (Concept design review) in March 2011. The DVAC documents were intensively discussed during the SKA dish CoDR in Canada in July 2011. There was a French-Chinese bilateral workshop held in France on Preparing for the SKA: Science and Technology, in November 2011, and a face to face meeting of a Dish proto-consortium between CASS and JLRAT in April 2012. China is now participating in the SKA WPC (Workpackage consortium) together with other international partners, i.e., Australia, Canada, South Africa etc.

3. Progress on FAST construction and Science team by middle 2012

Foundations were laid at the FAST site, Dawodang depression in Pingtang county, on December 26, 2008. After a more than 2 year feasibility study, preliminary design and site infrastructure preparation, the construction of FAST officially started in March 2011, i.e., on-site earthworks for 18 months at a cost of about 15 M US dollars (Fig. 7).

Fig. 7 A snap shot of the Dawodang depression in April 2012: all the earthworks have nearly been done at the FAST site.

Meanwhile, some engineering experiments are being undertaken at the FAST site, for example, a full-scale model of a reflector element was assembled (Fig, 8, left panel), measurements of the shape of the reflector element were performed, a basic control network for measurements established (Fig. 8, right panel), anchors for the cable-mesh reflector and actuators were tested on site, etc. While taking its long march to the SKA, China has promoted the FAST project as the following shows

- 1993.09 LTWG at URSI GA participation
- 1994.11 Proposal & Concept of KARST
- 1997.08 FAST concept completed
- 1999.04 CAS funding awarded to FAST pre-research
- 2006.03 International review panel met
- 2007.07 Funding Proposal approved
- 2008.10 Feasibility Report approved
- 2008.12 Foundation laid

- 2009.02 Preliminary design approved
- 2011.03 Construction started
- 2016.10 Commissioning expected
- 2016.11 SKA 1 construction underway with participation of FAST engineers

Fig. 8 At the FAST site, a full-scale reflector element was set up (left panel); the basic control network for the measurement system established for use (right panel).

Based on the interests of the Chinese radio astronomical community and the requirements of the FAST early science, a basic research team has been formed with funding awarded by the 973 Program of the MOST, about 5 M US dollars for the next five years 2012-2016, aiming to study six subjects: pulsars and theories, from atoms to stars: study of ISM and star formation, galaxy evolution, cosmology and dark matter, radio spectroscopy and masers, low frequency receiver array and VLBI system.

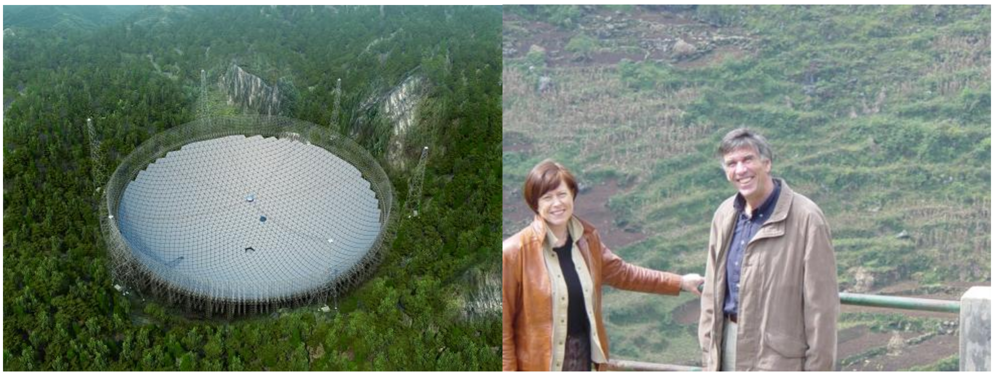

Fig. 9 The coming big dish, FAST, awaits Richard Schilizzi's revisit with his wife in 2016, while the SKA phase 1 is under construction.

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