Chinese concept for SKA:

Kilometre-square Area Radio Synthesis Telescope

National Astronomical Observatories, Chinese Academy of Sciences, Beijing 100012, China

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Abstract

A Five hundred meter Aperture Spherical Telescope (FAST) is proposed to be built in the unique karst area of southwest China, and will act, in a sense, as a prototype for the Square Kilometre Array (SKA). It will be over twice as large as the Arecibo radio telescope coupled with much wider sky coverage. Technically, FAST is not simply a copy of the existing Arecibo telescope but has rather a number of innovations. Firstly, the proposed main spherical reflector, by conforming to a paraboloid of revolution in real time through actuated active control, enables the realization of both wide bandwidth and full polarization capability while using standard feed design. Secondly, a feed support system, which integrates optical, mechanical and electronic technologies, will effectively reduce the cost of the support structure and control system. Pre-research on FAST has become a key project in the Chinese Academy of Sciences since 1999, and great progress has been achieved.

Keywords: Spherical telescope, karst depression, active reflector, cable support, scaled model

1. Introduction

In 1993 a large radio telescope, (LT, namely SKA since 1999), was proposed by astronomers from 10 countries at the 24th General Assembly of URSI. The SKA would be a telescope array with a total (effective) collecting area of about one square kilometre. There are various concepts worldwide to realize the SKA project. Efforts have been made extensively, i.e., in project teams of the Netherlands (wide-band phased array), Australia (an array of spherical Luneburg lenses, and a parabolic cylindrical reflector), Canada (large adaptive reflector of very long focal length), China (Arecibo-style dish), United States (Allan telescope array), India (an array of steerable parabolic dishes) etc. (details see http://www.skatelescope.org). In this paper we will summarize the Chinese concept for the SKA, KARST (Kilometre-square Area Radio Synthesis Telescope).

Chinese astronomers are going to build a set of large (Arecibo-style) spherical reflectors by making use of the extensively existing karst landforms, which are bowlshaped limestone sinkholes named after Karst, a Jugoslavian geologist. We refer this as Kilometre-square Area Radio Synthesis Telescope approach. The KARST project would be consisted of about 30 individual elements, each of roughly 200 m in diameter. As a forerunner for the KARST, a Five-hundred-meter Aperture Spherical Telescope (FAST) is planned to be constructed as a National Megascience Project of China, with an estimated cost of ~60 M US$ around the year 2006.

Some basic parameters of the FAST are demonstrated in Fig.1: a main spherical reflector radius of R=300 *m*, a total of up to 500 *m* projected diameter, and an effective aperture of about 300 *m*. Since the focal length of FAST is to be set < R/2, a portion of the parabola lies above the sphere. Then the two curves have three points of intersection, the first being at the common point of tangency (the point of osculation) and two more points, on opposite sides of the first, that move away from it. Somewhere between these points and the point of osculation the displacement between the two curves clearly reaches a maximum. The geometrical configuration in Fig. 1 will enable the FAST to have a larger sky coverage (> 40° zenith angle) than the Arecibo telescope (~ 20° zenith angle), and the simplified feed system will continuously cover most of the frequency range between 200 and 2000 *MHz*, with possible capability up to 5 or even 8 *GHz* depending upon the cost. The FAST obviously will achieve the largest collecting area in the world.

2. Site survey

A large number of karst depressions in Guizhou province, at least 400 depressions at Pingtang and Puding counties, were investigated with Remote Sensing (RS), the Geographical Information System (GIS) and on-the-spot observations, and selected as candidate site locations for the SKA. More than 10 depressions were imaged at the high resolution of 5 *m/pixel*, showing suitable profiles for a large spherical reflector.

A series of measurements at various sites has been carried out to check on their suitability, from the point of view of radio interference, for realizing the FAST/SKA. The first measurements were made at 8 karst depression sites in Nov. 1994 in both Pingtang and Puding counties. Further measurements were made in March 1995 for a period of one month in an attempt to understand distance effects. In June 2000, we re-monitored half of the above sites to see the change of interference with time. Due to the remoteness of this region and local terrain shielding of karst hills, preliminary results of radio interference monitoring are quite promising.

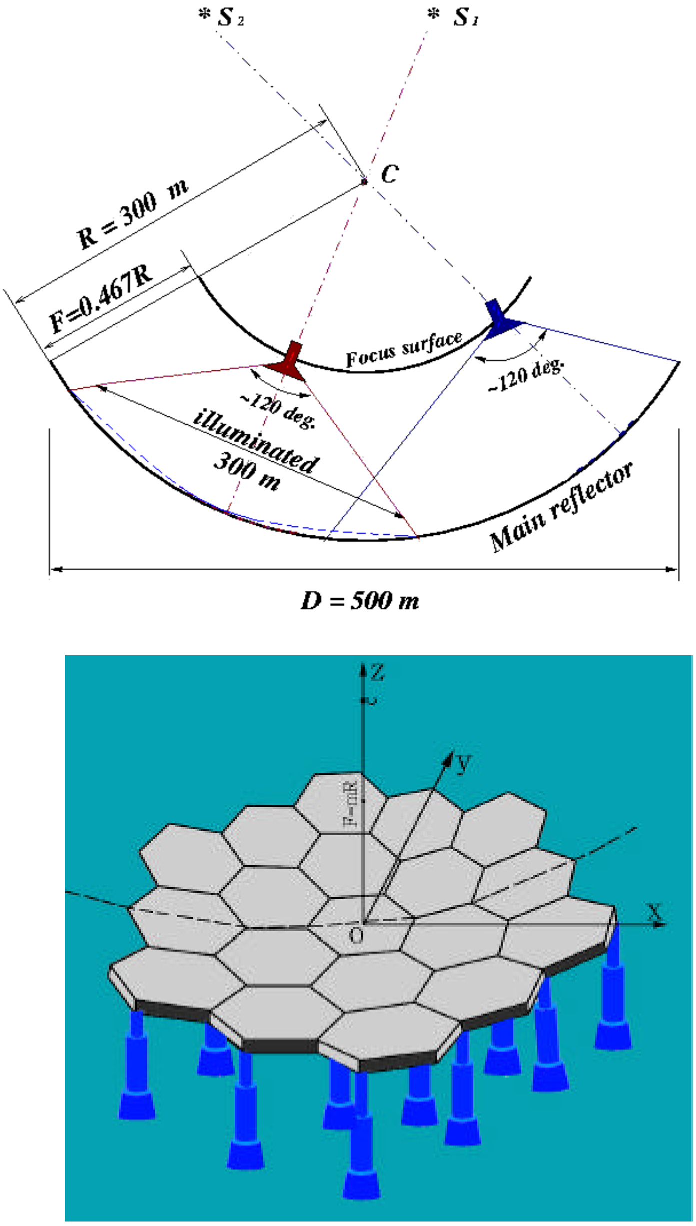

Fig.1 FAST concept and its geometrical configuration

3. Active main spherical reflector

It is well known that the central part of a spherical surface deviates little from a parabolic as a proper focal length is chosen, based on which, a novel design for a giant spherical reflector is proposed. The illuminated part of the main spherical reflector (Fig.1) is to be continuously adjusted to fit a paraboloid of revolution in real time by actuated active control, synchronous with the motion of the feed while tracking an object. A standard feed system can then be adopted to achieve a broad bandwidth and full polarization capability through the total elimination of spherical aberrations.

For the maximum apparent motion of the celestial objects, the rate of variation is found to be very small, lower than 5 *cm/min*, which enables inexpensive solutions of the mechanical control. The time required to switch between target sources, which lie far apart, is expected within 10 minutes.

For construction, it is necessary to divide the giant main spherical surface into smaller elementary units. Each element is a small part of the spherical surface and its curvature should be optimized to get the best fit to the paraboloid. Each element has three actuators to fix its position and connect it with adjacent elements, and there would be an average of one actuator per element as shown in Fig.1. The support with its actuator is directed towards the center of the sphere. A control system based on one of the up-to-date field bus technologies is suggested. If the *r.m.s* of the aperture is expected to be smaller than ~4 *mm* at 5 *GHz,* the largest dimension of each element should not exceed 15 *m.*

4. Feed support

FAST can be seen as an "Arecibo-type with active main reflector", the telescope is "pointed" by moving the feed cabin, while the reflector surface is deformed in synchronism with the feed pointing motion.

4.1 Cable support system

A new design for the feed-support structure (Fig. 2) for FAST has been proposed by using six suspended cables connected to mechanical servo-control systems. Compared with the Arecibo 305 *m* radio telescope, the total weight of the feed support system could evidently be reduced by 2 orders or more with such a design, probably from nearly 10,000 (if Arecibo-like support employed) to a few tens of tons. The tracking will be by means of integrated mechanical, electronic and optical technologies, i.e., optomechatronics.

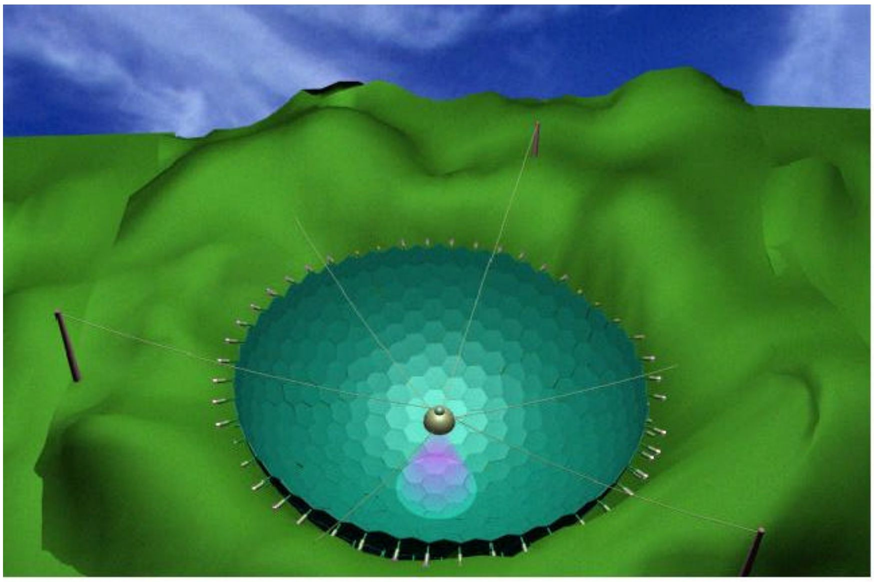

Fig.2 Cable support system without a platform

The whole system will mainly consist of three parts: firstly, the six cables will be driven by six sets of servo-mechanisms controlled by a central computer, so that the movement of the focus cabin along its caustic trajectory can be realized. Given the difference between the apparent and required positions, where the feed (cabin) should point, the central computer will drive each servo-mechanism to adjust the position of the feed. Secondly, a group of receivers with multi-beam feeds will be mounted on a stabilizer in the focus cabin. This is to provide a second adjustment, since the cabin driven by cables alone may not achieve the pointing accuracy required. A laser ranging system, being the third part, will be adopted to accurately measure the position of the feed in real time. The information will be fed back to the central computer for global loop control.

To demonstrate the design, a 5 *m* model has been built with success to precede constructing a 50 *m* model. For FAST the focus cabin can be positioned to some tens of centimeters accuracy by cable-driven only, and then further to millimeter accuracy with a fine-tuning stabilizer, i.e., the Stewart platform. A typical Stewart platform consists of six variable-length actuators connecting a mobile plate to a base. As the lengths of the actuators change, the mobile platform is able to move in all six degrees of freedom with respect to the base.

4.2 Cable car configuration

A small cable car, to serve as the focus cabin housing the feed and receivers, is to be driven by eight cables. Two pairs of parallel supporting cables will be suspended from two pairs of opposite towers (instead of the three in the concept discussed above), while another four downward cables are securely fastened to four anchors which are symmetrically arranged about the main spherical reflector. The lengths of the connecting cables would be adjusted appropriately as the cabin location changes. Such a design aims to increase the stiffness of the platformless cable support structure discussed above.

Positioning of the cabin would be achieved by driving the car on two crossed sets of supporting cables, which is like a trolley on the cable-way in mountains. The car can move in two directions with the two sets of suspension cables as tracks. And the cabin has two rotational degrees of freedom relative to the cable car, which allows the feed to be arbitrarily pointed, irrespective of what the orientation of the cable car is. Rotation of the feed can be realized by a special mounting in the car, the axis of which should intersect the center of gravity of the cabin. Rotating the feed about its phase center is a way to gain a significant increase in scan range. Actuators are to be employed for actively controlling any oscillations of the cabin induced by the motion.

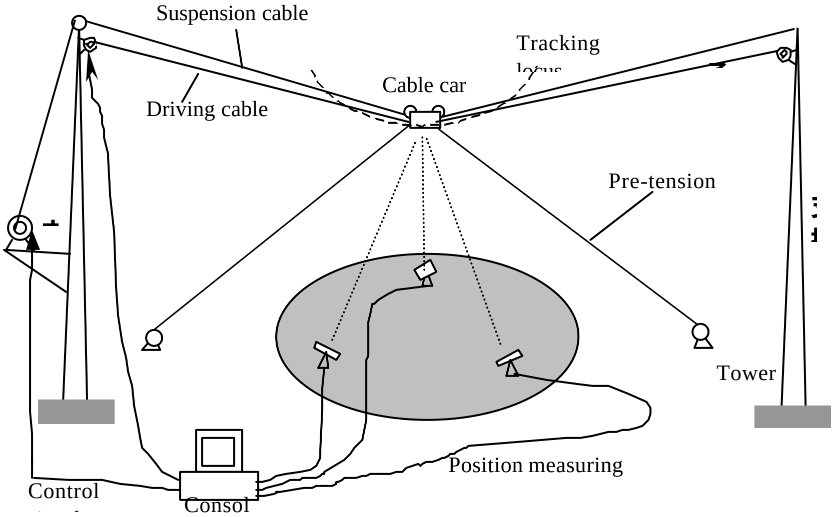

Fig. 3 The general assembly of the cable car feed support configuration

The cable-car configuration is demonstrated in Fig. 3. The pre-tension cables are introduced to adjust the stiffness of the feed support structure. The effect of the pre-tension cable for suppressing unwanted vibration can be obtained by finite element dynamic analysis with the excitations generated according to the measured wind conditions of candidate sites. Though a precision of about 0.5 *m* can be expected for reasonable tension level in the stabilizing cable, it is wise to have a secondary feed stabilizing device instead of increasing the stiffness of the whole structure to an unrealistic level. Trim masses can be used to balance the static load of the suspension cable for energy efficiency during operation of the telescope.

The main advantages of this cable-car configuration are the following: firstly, the maximum length of cable extension will be relatively short, and the change may be as small as ~30 *m* when observing a target. Secondly, the downward cables (with a radius of ~1 *cm* in such a design), can be used to adjust the stiffness and improve the dynamic characteristics of the system. Thirdly, the car could be used as a crane during construction and maintenance of the main spherical reflector, and access for maintenance can be achieved by lowing the car down to a ground platform close to the tower foot.

5. Receiver system

The receivers are to be mounted on a stabilized station, connected to the main body of the focus cabin as a Stewart Platform. A collaboration on FAST was established between Beijing Astronomical Observatory (Now the National Astronomical Observatories) and the University of Manchester's Jodrell Bank Observatory (JBO) by a memorandum of understanding signed in July 1999. The joint discussion of the low noise receivers for FAST are based on the use of existing, proven technology, to minimize the technical risk for the project.

6. FAST science

The collecting area of a telescope is a figure of merit of that instrument's capability. In this context it should be remembered that if we have twice as much sensitivity, for uniformly distributed object we will look twice as far in space, and should find eight times as many objects. It is notable that almost all of the outstanding astronomical discoveries could not have been anticipated at the time that a telescope was being planed.

The study of atomic hydrogen (HI) through the 21 *cm* line has been one of the most fruitful lines of radio astronomy research. HI emission provided us with our first glimpse of the obscured disk of the Milky Way right to the other side of the nucleus, it enabled kinematic studies of other galaxies well beyond their optical disks, it gave some of the strongest evidence for the existence of "dark matter", and has led to the discovery of some of the most massive galaxies known. A large fraction of the total baryonic mass of the Universe may be locked up in a sea of faint but gas-rich objects. FAST may discover faint gas in the outer disks of galaxies, and provide clues to the mystery of dark matter. FAST can find HI-rich galaxies whose distances can be determined by the Tully-Fisher method, providing a measurement of the cosmological density parameter.

The 18 *cm* OH line has been important for the study of star formation and evolution, and the megamasers found in some galaxies make them visible to great distances. HI and OH investigations with FAST will detect objects to red-shift z ~1 and beyond, and will provide astronomers with fundamental data about the universe.

Most pulsars have been discovered in large-scale surveys using single dish telescopes. FAST would provide the first opportunity to investigate in some detail the pulsar population in another galaxy. The FAST will be especially effective in deep surveys for sources such as rare types of pulsars and neutral hydrogen clouds at moderately high red-shifts. Details in the structure of individual pulses, or in their polarization, might be vital. Such measurements rely on raw sensitivity: a single pulse can only be observed once. FAST will give us the best information on the greatest number of pulsars.

An important question to which FAST might provide an answer is, at what epoch did primordial gas come together in cluster-sized clumps prior to forming the clusters of galaxies we see today ? It is expected that the pre-cluster agglomerations of gas will have sizes of a few to tens of arc-minutes and hence be well suited for detection with FAST.

A 300 *m* telescope in combination with a 25 *m* one has the same response as two dishes of 87 *m.* FAST as a VLBI station will be the hub of the most highly sensitive network.

Studies of distant planets in the solar system are essential for understanding its evolution, the origins of life, and for investigating how the deep space environment would affect human beings with a view towards potential colonies in space. FAST will play an important role in the deep space network, and in SETI research.

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