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21 世纪的射电天文学：仪器设备发展

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摘 要

回顾了射电天文设备的观测能力的提高和将遇到的限制因素。评述全波段射电天文学的大型射电天文设备计划和各国射电天文学发展的一些共同特征，提出了值得借鉴的经验，为我国射电天文学的发展提供参考意见。

Radio Astronomy in the Next Century: Instrumentation Development

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Abstract

After a review of the advances in the observing capability of radio astronomy and its future, we give a description of large radio astronomy projects covering all-wavebands suggested and discussed in recent twenty years. Some common features in the development of radio astronomy in various countries are summarized. We mention the experience which can be used for reference in the development of Chinese radio astronomy.

1 Introduction

Three score years have elapsed since the founding of radio astronomy. Although radio astronomy is still younger than optical astronomy, it is already a sub-discipline of modern astronomy. Radio astronomy observatories and institutes were developed independently parallel to optical astronomy ones in the world. The observational capability of radio astronomy is determined mainly by spatial resolution and sensitivity of radio telescope. Radio interferometry, especially VLBI, has made it superior to optical astronomy in spatial resolution and initiated imaging of the physical process in AGNs. The sensitivity is also increasing very rapidly.

This paper is aimed at discussion of some common features in the development of radio astronomy for reference in the consideration of surveying the Chinese radio astronomy.

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2 Advances in the Observing Capability of Radio Astronomy and Its Future

The observing capability of radio astronomy instruments includes sensitivity, spatial resolution, quality of image, spectrum and etc. Sensitivity and resolution are main performances of radio telescope among them. The so-called " all-wavebands " of radio astronomy have extended to decameter, meter, decimeter, centimeter, millimeter and sub-millimeter, i.e., from 30 meters to 0.1 millimeter which are limited by ionosphere and atmosphere respectively. The sub-millimeter radio telescope can work at the wavelength of 0.3 millimeter now. Radio astronomy extended to sub-millimeter is realized only in recent decade. The spectral line of CO at 0.87 millimeter wavelength in Orion KL was first detected in 1977.

Sensitivity depends on the effective collecting area of the telescope, i.e., the effective aperture of the parabolic antennas or systhesis radio telescope and the system noise (including the noise of receiving system). The sensitivity has been improved with time exponentially. A factor of 10^{13} has been reached since the founding of radio astronomy, roughly from mJy to mJy. The collecting area of single-dish radio telescope remains at $10^4 m^2$ (or an aperture of 100m) in recent years. It is reported that even larger collecting area of 200000 m^2 (or aperture of 250m) at centimeter wavelength, of 20000 m^2 (or aperture of 80m) at millimeter wavelength and of 2000 m^2 (or 25m)at sub-millimeter wavelength were discussed. Such levels of large collecting area could be realized by active primary reflecting surface or synthesis array. The NRAO Green Bank radio telescope under construction uses active surface. Much larger collecting area should be realized by synthesis radio telescope.

The radio receiver noise limit will be quantum noise, $T = h\nu/k$, which is 4.8 K at the wavelength of 3 millimeter. At this noise level the contribution of ground noise picked up by sidelobes and backlobes of the parabolic antenna and emitters from space (satellite and spacecraft) will be dominant, and therefore undesirable structure of the antenna beam should be reduced to a minimum. An offset feed configuration will be used for Green Bank Telescope with a diameter of 100m which will be operational in 1995. It is an improvement for large radio telescope. This unblocked beam greatly reduces unwanted radio interference and undesirable astronomical signals in comparison with a conventional center-fed telescope, especially at low elevations. It can be seen that the only way to increase the flux density sensitivity is the construction of radio telescope with greater collecting area when the receiver noise approaches 3K cosmic background level. The present global VLBI array (EVN + VLBA + VLA + GBT) has a collecting surface area, which gives a sensitivity 1σ of some 7 μJy, using VLBA recording system and 8 hours observation. If the sensitivity continues to be improved exponentially, it will approach 0.03 μJy in the next century.

The improvement of resolution depends upon radio interferometry, especially VLBI. RADIOASTRON will make a resolution of 10^{-4} arcsec and reach μas by phase referencing. Resolution improves exponentially, and will approach 0.03 μas in the next century.

The quality of image is of essential importance for radio astronomy. Great progress has been made in the dynamic range of VLA images with sophisticated computer software and facilities. There has been an increase of 30 db in the dynamic range of VLA images and will approach 40 db in the next century. Colour radio image has been widely used in place of radio contour images. The colours have no real meaning but one can use colour coding in a variety of ways, such as radio intensity or brightness, radial velocity and so on for better physics interpretation.

3 Limitations of Observing Capability

The observing capability of radio astronomy is subjected to nature and man-made limits.

3. 1 Confusion

This problem has been discussed since 1950. Sensitivity should be matched by resolution. When two or more sources with different declinations are simultaneously present within the antenna beams, the fringe patterns with slightly different frequencies will be produced. The combined fringe patterns contain amplitude variations analogous to beat tones in acoustics, and the maxima in the output do not correspond to individual sources. In other words, there should be a match between resolution and sensitivity. It is estimated that at μJy level the distance between sources will be smaller than their size and real saturation of sensitivity may be reached.

3. 2 Scattering

Scattering effects are very strong at meter waveband. In some regions of the sky (e.g. the center of the Galaxy) the visible size may be limited by the interstellar scattering effects even at centimeter and millimeter wavelengths. The maximum baseline for space VLBI is now under discussion. Scattering may be an important limiting factor.

3. 3 Irregular brightness in the sky

Sky irregularity caused by atmosphere emission is well known. This limit may be overcome by various ways: beam switching mode of observation, multi- frequency observation, water radiometry and interferometric methods. However, it is reported by RATAN-600 that there is irregularity at 1-mK level at 7.6 cm on one degree scale with non-thermal spectrum. Moreover, at short wavelengths the Galactic cirrus emission has irregularities at 10-arcsec to 10-arcmin with strong inverted spectrum. It indicates that there is some optimal wavelength where these limits are minimum, probably at millimeter wave region. At all wavelengths there should be an absolute limit on sensitivity, on all scales set by predicted 3K-anisotropy at the level between 100 to 10 μK. It has been observed that large scale emitters appeared recently with nonthermal spectrum identified with walls of the void structure. Irregularity of the millimeter wave emission of the Galaxy may be caused by the irregularities of the line emission even in continuum type observation.

3. 4 Physical limits

It has been suggested that the brightness temperatures of radio galaxies and quasars are limited to 10^{12} K according to inverse Compton scattering of the radiating electrons, as the baseline of VLBI are constrained by the size of the Earth. Possible larger brightness temperature can be detected only by space VLBI, so that the theory could be demonstrated. Quite different limits caused by different means of observation may occur with even deeper penetration of radio astronomy up to the epoch when radio sources were not yet born.

It has been found from the very deep VLA surveys that there are no quasars at sub-mJy level. It is estimated that optical surveys will be limited by z=5.5 due to the dust absorption and only radio astronomy telescope can " see " farther.

In addition to nature limits, the interference problem, i.e., electromagnetic pollution makes the man-made limit. In fact, radio astronomy has been developing exponentially in parallel with the exponential development of the civilization on the Earth. Therefore, there is some crucial moment in the near future after which the real sensitivity will be less than before.

4 All-wavebands Radio Astronomy

The so-called all-wavebands astronomy is a phenomenon of the last three decades, which distinguishes modern astronomy from traditional astronomy only concerned with studying the optical radiation from objects in the space. The all-wavebands astronomy encompasses all the radiations emitted by celestial objects. They are γ rays, X-rays, ultravoilet, optical, infrared and radio waves. The rapid growth of the all-wavebands astronomy is partly due to the discovery of radio astronomy, which showed that there are non-optical radiations from the space. However, the development of all-wavebands astronomy depends upon a variety of types of telescopes and detectors, especially the new detectors for many wavelengths must be flown well above the atmosphere. In fact, the space astronomy could not be pursued until the last twenty years.

All-wavebands radio astronomy encompasses the wavebands ranging from sub-millimeter to 30-meter wavebands. Thus the all-wavebands of radio astronomy indicate decameter, meter, decimeter, centimeter, millimeter and sub-millimeter. The forms of the antennas and detectors can be very different for various wavebands, and therefore it is difficult and unnecessary to build a radio telescope operating at all-wavebands. Centimeter and millimeter parabolic antennas are most common at radio observatories, which are dish-shaped and similar to traditional telescopes in appearance. However, a number of single wire dipole aerials will act as antenna at very low frequencies.

Large instruments for radio astronomy were suggested in the last 25 years (until 1990):

(1) Decametric waveband projects:

(a) Space VLBI: 5 orbiting dipoles, 3 – 300 MHz range (NASA);

(b) Space ASTRO-ARRAY: for whole radio frequence range. 1000 × 30m dishes at many Earth diameters distances(NASA).

(2) Meter waveband projects:

(a) Giant Equatorial Radio Telescope (GERT):1 × 10^6m^2 collecting area, arcsec resolution, 1 μJy sensitivity. A smaller version GMRT (30 × 45m dishes) of this project is under construction in India and will be operational in early 1995 ;

(b) Arcsec Synthesis Array from 10 × 100m telescopes, λ = 1m (former USSR, Pushchino);

(c) The ground array with 10^6m^2 collecting area: 1 arcsec resolution (former USSR).

(3) Decimeter waveband projects:

(a) Pulkovo 1964 RATAN-type project: 20km size, 1 arcsec resolution, 2 × 10^6m^2 collecting area, 21 cm – 1 m range;

(b) CYCLOPE project (USA): 20cm SETI programme.

(4) Centimeter waveband projects:

(a) Pulkovo cm, RATAN-600-like ring radio telescope: 0.5 × 10^6m^2 collecting area, $\lambda \geq 3$ cm, 1 arcsec resolution;

(b) QUASAR project: 10×32m VLBI dedicated array for geodesy and time service, $\lambda \geq 1.35$ cm;

(c) RADIOASTRON project: space VLBI, 77000 km maximum baseline, $\lambda \geq 1.35$ cm, 10 m dish in space;

(d) VSOP project: space VLBI, 8 m on the one Earth radius orbit, $\lambda \geq 1.35$ cm;

(e) IVS project: space VLBI, 20m class dish in 200000 km apogee orbit, $\lambda \geq 3$mm;

(f) 300 m Arecibo-type dish in Brazil, $\lambda \geq 1.28$ cm.

(5) Millimeter project:

(a) 70 m dish for less than 1 mm (former USSR, first version under construction in the Middle Asia);

(b) 50 m dish for less than 1 mm (USA);

(c) 54 m Arecibo-type dish for 1 mm with 2.6 m on-axis optical telescope in Armenia(former USSR);

(d) Many mm and sub-mm dishes and arrays in USA programme.

Table 1 Large radio telescopes in 2000

(collecting area $\geq$ 2000m^2, or D(equivalent)$\approx$ 50m)*

Station	Institute	Diameter(m)	Shortest wavelength	Collecting area (10^3m^2)	References
Effelsberg	MPIfR	100	4-7 mm	7.8	[5]
GBT	NRAO	100 (active surface)	$\sim$ 2.6mm	7.8	[4]
WSRT	NFRA	93(equ.)	>3.6 cm	6.8	[5]
VLA	NRAO	125(equ.)	1 cm	13.0	[4]
Jodrell Bank	NRAL	76	6 cm	4.5	[5]
GMRT	RAC	45($\times$30)	$\geq$ 18cm	48.0	[11]
Arecibo	AR	210	$\leq$ 3 cm	50.0	[11]
RATAN-600	PO	600	8 mm	14.0	[9]
Nobeyama	NRO	45	1.3 mm	1.6	[7]
Bearlake	(former USSR)	64	1.3 mm	3.2	[10]
Evpatoria	DSTS (former USSR)	70	1.3 cm	3.8	[10]
Ussuriysk	DSTS (former USSR)	70	1.3 cm	3.8	[10]
Samarkand	DSTS (former USSR)	70 (active surface)	1.3 mm	3.8	[10]
Ooty	NRAC	140	1 m	15.0	
MMA	NRAO	8($\times$40)	1 mm	2.0	[9]
Armenia	Arecibo type (former USSR)	54	1 mm	2.3	[1]
Itapetinga	IRAO (Arecibo type)	300	$\geq$ 1.28 cm	70.0	[1]
Nancay	RAO	200($\times$35)	18 cm	7.0	[5]
Culgoora	ATNF	22($\times$6)	3 mm	0.7	[6]
ARO	ARO	37	2.6 mm	1.0	[9]
Parkes	ATNF	64	3 cm(64m) 7 mm(44m) 3 mm(15m)	3.2	[6]
Pico Veleta	FGSMRAO	30	0.8 mm	0.7	[9]
Plateue de Bure	FGSMRAO	15($\times$3)	0.8 mm	0.5	[9]
MRT	INO	30	1 mm	0.7	[9]

* 1. List of Institutes

AR	Arecibo Observatory
ARO	Algoquin Radio Observatory
ATNF	Australia Telescope National Facility

DSTS	Deep Space Tracking Station
FGSMRAO	France-Germany-Spain Millimeter Radio Astronomy Observatory
INO	Iraqi National Observatory
IRAO	Itapetinga Radio Astronomy Observatory
MAO	Radio Astronomy Division, Meudon Astronomy Observatory
MPIfR	Max-Planck Institute for Radioastronomy
NFRA	National Foundation for Research of Astronomy
NRAC	National Radio Astrophysics Center, India
NRAL	Nuffield Radio Astronomy Laboratories
NRAO	National Radio Astronomy Observatory
NRO	Nobeyama Radio Astronomy Observatory
PO	Pulkovo Observatory

*2. ~ 30m millimeter antennas are also included. Equivalent diameter is used for antenna array.

These are parts of large projects suggested until 1990. Some of them are under construction. Among the new projects suggested afterwards, Green Bank Telescope (GBT) is the most prominent. This telescope incorporates two main features, an unblocked aperture and an active primary reflecting surface. The unblocked aperture allows the structures from the antenna beam to be removed and can be protected against external radio interference and noise. The incorporation of active surface provides a means of circumventing the usual gravitational and thermal limits to passive antenna structures of this diameter and upgrading the antenna surface accuracy to reach a value allowing for operation with reduced efficiency as good as 2.6 mm. This will be a milestone of the development of the technology for large diameter antenna. The homology design of the Effelsberg 100 m antenna was regarded as an innovative concept. If the active surface in use for optical telescope can be adopted to antenna with large diameter successfully, it should be possible to make a breakthrough in the construction of single-dish antenna with more than 100 m diameter. It is required to use laser ranging system and microwave holography for accurately setting the surface under various weather conditions so that the antenna will be able to work at expected shortest wavelengths with optimal efficiency.

Synthesis radio telescope for large collecting surface by combination of a number of small antennas area still has vitality. The synthesis technology uses sophisticated electronics to avert from mechanical construction difficulties successfully, so new projects such as GMRT (Giant Meter Radio Telescope) in India, millimeter and submillimeter arrays are synthesis arrays.

VLBI Technique which developed in recent 25 years is the basis of Earth-sized global synthesis radio telescope. Roughly speaking, the array sensitivity of a VLBI network is related to the products of interferometer elements, $\sqrt{\sum A_i A_j}$ (A_i and A_j denote the effective area of antennas). It can be seen that smaller antenna has only a little contribution to the array. Nowadays the elements of a centimeter VLBI network are usually not smaller than 25m antennas. Furthermore, the contribution of an antenna to the VLBI network not only depends on the size of the antenna but also its geographical location. For example, the Shanghai 25m antenna in the European VLBI Network makes better resolution and Urumqi 25m antenna makes better uv coverage. However, the performances of the antennas themselves in the global VLBI network would play more important role.

It is beyond doubt that there is a trend of joint VLBI observations involving existing radio telescopes of centimeter and millimeter wavebands in the world. Consequently, VLBI is always considered for new projects of radio telescopes in many countries. For instance the aperture of the antenna should be considerable large and VLBI facilities should be equipped with. But it should not be ignored that VLBI observing time is only a small fraction for a radio telescope because non-dedicated VLBI network works on the basis of part-time. The global VLBI has four sessions a year, and individual radio telescopes are usually not scheduled for full-time during each session on average, only several days each session probably. The scientific benefit of the radio telescope will be very small if it only has VLBI capability. We will discuss it later. In table 1, we show large radio telescopes in 2000, having collecting area of 2000 m^2 , equivalent to an aperture of 50m antenna. Only antennas of meter, centimeter, millimeter, and sub-millimeter wavebands are included. In addition to the attention to the aperture of 50m, we should also notice the shortest wavelengths, because the antennas with shortest wavelengths of less than 2.6 mm should have stronger vitality, they will be key elements in the millimeter VLBI observations in the next century.

At this point we have reviewed the development of all-wavebands radio astronomy with emphasis on large and sensitive instruments. General speaking, the scientific objectives for radio astronomy are plenty of molecular spectral lines at millimeter and sub-millimeter wavelengths and synchrotron radiation at centimeter and longer wavelengths.

The " sub-arcsecond radio astronomy " conference held at Manchester in July 1992 divided observing facilities in terms of resolution. As a matter of fact, the conference asked for research papers on the interaction between radio and optical observations at high resolution from observations by different telescopes, namely, optical telescope (HST) and VLA with a resolution of $\sim 0''.01$, MERLIN synthesis radio telescope with a resolution of $\sim 0''.01$, and VLBI with a resolution of $0''.001$. In fact, there have been multi-resolution observations of a variety of objectives, such as AGN, gravitational lens, extragalactic supernova, spectral lines and continuum radiation of stars and molecular clouds, jet of stars, the Galactic center and interstellar scattering, and accurate astrometry and proper motion of pulsars and etc. The fundamental methodology is image processing. It is well known that it is difficult for single-dish radio telescope to make image of radio sources with high resolution. However, sub-arcsecond radio astronomy depends mainly upon synthesis imaging.

5 The Growth of Radio Astronomy in Various Countries in the World

In this section, we give a general description of the growth of radio astronomy in various countries, so as to explore some common features of experience that can be used for reference in the consideration of Chinese radio astronomy.

The first common feature is that most countries have a radio astronomy center, a radio astronomy observatory or institute. For example, there is Nuffield Radio Astronomy Laboratories in the United Kingdom. The 76 m radio telescope at Jodrell Bank upgraded in its performance and the Cambridge 25 m antenna completed recently. As a result both the resolution and sensitivity of MERLIN were improved and short baselines essential for imaging extended sources were added into the EVN uv coverage. The fact that the resolution of MERLIN is between those of VLA and VLBI is unique complement to EVN. The radio astronomy center in the United States is NRAO, which runs Green Bank, VLBA and Kitt Peak radio observatories. Others are Westerbork synthesis radio observatory under NFRA in Dwingeloo, the Netherlands, Radio Astronomy Institute, Bologna, Italy, Onsala Space Observatory, Sweden, Nobeyama Radio Astronomy Observatory, Japan and etc. The large project GMRT (Giant Meter Radio Telescope) belongs to National Radio Astrophysics Center, India.

As mentioned above, radio astronomy is a rather new branch of astronomy which rose in the early 1930s and strongly depends on the development of electronics and computer techniques. In comparison with the traditional optical astronomy, radio astronomy is new and far from mature. As a result, a number of radio astronomers devoted themselves to instrumentation. M. Ryle, a winner of Nobel Price, devoted his large energies for many years to the development of synthesis radio telescope and obtained many high resolution images of extragalactic radio sources including Cygnus. Until now VLBI researchers have to be familiar with complicated VLBI packages and spend a considerable time on data reduction. The reason that radio astronomy observatories or institutes are independent of traditional observatories is that radio astronomy has its own speciality in techniques. Therefore in most countries, there are radio astronomy centers, which are vital to the development of radio astronomy.

Radio astronomy center implies concentration of funding by the state and of operating large radio telescopes, and in turn forming an academic research center of higher level. Also an electronics laboratory of appropriate scale is required to match the radio telescope so that the observing capability of radio astronomy can be upgraded to keep pace with advanced level. These are the fundamental essentials for a successful radio astronomy observatory in most countries.

The second common feature is that independent observing system is required. The observation of continuum astronomy needs image of source, but medium-sized radio telescope has very low resolution and is usually unable to make images. However, modern radio astronomy mostly depends on sub-arcsecond resolution and hence for continuum astronomy medium-sized radio telescope can be used only as elements of synthesis radio telescope, traditional or VLBI. In this sense, an antenna is not an observing system by itself but an element of an array. Single-dish radio astronomy observation encompasses only total flux density and spectral line measurements. Total flux density measurements, such as monitoring of variable radio sources, light curves and etc. are typical single-dish radio astronomy. Delicated VLBI radio telescope depends on the VLBI network, and therefore it is not an independent observing system, and leaves unused for the most time. Its scientific benefit is low and very few such cases exist in reality. In fact, most radio telescopes work in single-dish radio astronomy mode, so telescope terminals for this purpose are indispensible.

In many countries, there are both single-dish and synthesis radio telescopes, for example, in the United States, the United Kingdom, the Netherlands, Japan, Australia and India. Examples of very large antennas are RATAN 600 in former USSR and 100m antenna in Germany. These are independent observing systems which have observing capability for a wide range of astronomical research.

The third common feature is that the main research field of radio astronomy observatories is astrophysics which is the principal aspect of modern astronomy. In fact, radio astronomy is a branch of astrophysics. Besides, the very high resolution makes precise radio astrometry possible. Because of the similarity of techniques between VLBI astrometry and VLBI geodesy, research on celestial reference system is also related to VLBI geodesy. Geodesy studies geodynamic and static phenomena regarding the shape and orientation of the Earth.

The fourth common feature is that VLBI research is always the programme in the development of a radio astronomy observatory in every country. It is recognized that VLBI is a new stage in the development of radio astronomy techniques. It is worthy of mention that each country has its radio astronomy center, and large projects should be an action of the whole radio astronomy community rather than that of an individual astronomical observatory.

6 Discussion

6. 1 Better sensitivity and resolution

The aperture of large steerable parabolic antenna may break through 100 meters. In 1979, an antenna with 128 m diameter was considered at Special Astrophysical Observatory in the former USSR, to supply the RATAN-600 as complementary facilities, especially for VLBI and spectroscopy. Millimeter antenna with a diameter of 70 m and operating at 1 millimeter wavelength is under construction. The GBT in the United States is a 100 m fully steerable telescope, with a goal of allowing for operation with reduced efficiency at as low as 2.6 millimeter wavelength. In future 100 m antenna working at millimeter wavelength will not be difficult to construct. This progress will in turn promote the global VLBI observation to operate at millimeter wavelength. Antenna of 60 m class operating at centimeter wavelength only will not be able to meet the needs of frontiers research on radio astronomy. In order to achieve the goal of collecting area $1 \times 10^6 \mathrm{m}^2$ of the telescope, synthesis technique is necessarily required. It is now not a difficult task to construct a telescope of 50 – 60 meter class operating at 1.3 – 2.6 millimeter wavelengths in some advanced countries. The scientific goal of this kind of medium-sized antenna should be millimeter wave astronomy and VLBI as well.

As electromagnetic pollution is increasing exponentially, the radio frequency interference environment should be taken into consideration for a new radio telescope.

6. 2 International experience in the development of radio astronomy

Radio astronomy as a sub-discipline of astronomy (mainly astrophysics) will continue to exist and develop. The observing capability is improving exponentially, and that implies its non-maturity and technicality. Nevertheless, the maturity of radio astronomy is only next to that of optical astronomy in the so called all-wavebands astronomy. The fact that every country has its own radio astronomy observatory devoted to radio astronomy research is a long history. Radio astronomy observatory usually has electronics laboratory of its own. As a matter of fact, radio astronomy is a result of a combination of astronomy and electronics. A radio astronomy center is essential in a country to muster up researchers to plan new large projects, which usually needs huge funds and state-of-the-art technology. The radio astronomy center should also play an important role in statewide academic activities. In fact, single-dish radio telescope, synthesis radio telescope, millimeter radio telescope and VLBI are products at successive stages in the course of the development of radio astronomy and they have intrinsic relationships and are inseparable in science.

6. 3 Non-astronomy use of radio telescope

By non-astronomy use of radio telescope we mean VLBI geodesy. VLBI geodesy research is similar to astronomy in many aspects in VLBI techniques. For example, VLBI wideband recording system MK3 was initially developed for geodesy, and also for astronomy. However, the requirements of astronomy are quite distinct from geodesy in data reduction and network layout. In addition, a 20 m antenna is enough for geodetic VLBI, on the contrary, large antenna is not good for geodesy because it usually slews slowly, while quick slew rate is essential of geodesy for a number of repeated observations of reference sources to improve the accuracy of measurements. Antennas constructed for dedicated geodetic VLBI usually take part in NASA project for earth surveying.

Examples are Wettzell 20-meter antenna in Germany and Mizusawa 15-meter antenna in Japan. These antennas are small and unable to operate at millimeter waveband, so they will not play important roles in the global VLBI array.

The Shanghai and Urumqi 25-meter antennas are largely constructed for geodetic purposes and also partly for astronomy research. Although Shanghai antenna has become a member of the EVN, it is not in use as a single dish radio telescope regularly. It has been largely involved in the NASA crustal dynamics programme. By the way, as a result of the swift growth of GPS geodesy, the VLBI mobile station will soon be out-of-date. NASA vigorously developed VLBI mobile stations fifteen years ago for prediction of earthquake of Los Angles area operated along San Andreas Fault. However, this large scale and prolonged project has proved to have little success.

6. 4 Radio astronomy in China

Radio astronomy in China has grown out of nothing and from small to large since 1950s. Now Miyun meter waveband synthesis radio telescope, Qinghai millimeter radio telescope, and Shanghai and Urumqi radio telescopes with VLBI facilities have been established. The crux of the problem is that because of historical reason there is not a radio astronomy center. The Chinese radio telescopes are all operated by traditional astronomical observatories separately. Further discussion on this problem is beyond the scope of this paper.

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