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The Miyun 50 m Pulsar Radio Telescope

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Abstract The National Astronomical Observatories, Chinese Academy of Sciences is now building a 50 m radio telescope at the Miyun Station. In this paper, we give a brief introduction to the Miyun Station. The main specifications and the status of construction of the 50 m radio telescope are described. We are now building an L-band pulsar receiver for this new 50 m telescope. The status of this receiver project is also described. The 50 m telescope, together with the pulsar receiver, will make it a powerful radio telescope to carry out pulsar observations and researches in the near future.

Key words: pulsars: general — telescopes

1 INTRODUCTION

Chinese astronomers proposed to build a dedicated pulsar radio telescope at the Miyun Station in the beginning of the new millennium. The Miyun Station is one of the observational bases of the National Astronomical Observatories, Chinese Academy of Sciences (NAOC). An invitation to tender for conceptual design of the 50 m telescope was sent to four domestic companies/institutes. The conceptual designs was completed in 2002. At that time, we were aiming at a light-weight low-cost 50 m antenna. The main reflector was made of metal wire mesh.The telescope, which was supposed to work up to 3 GHz, will be the largest single dish telescope in China.

At the end of 2002, the Chinese lunar mission showed interest in the Miyun 50 m telescope. The Chinese lunar orbiter requires a downlink scientific data rate of about 3 MB s^{-1}. This high data rate at the earth-moon distance is difficult for the current Chinese ground stations, that normally have antennas with diameter of about 20 to 30 meters. The Chinese lunar project team and the radio astronomers gathered together to investigate the possibility to upgrade the design to make the 50 m antenna suitable for X-band operation, and as a result, it was decided to build a somewhat better antenna. This improved 50 m antenna will serve for future Chinese space missions and radio astronomical observations as well.

In 2003, the Chinese Academy of Sciences (CAS) approved the building of an L-band pulsar receiver as one of the key projects of the Knowledge Innovation Program (KIP) of CAS. This receiver will be installed on the 50 m radio telescope, to conduct pulsar observations.

In the following section, we give a short introduction to the Miyun Station. In the third section, the main specifications of the 50 m telescope, the current status of the construction and a possible upgrading plan in the future are described. The pulsar receiver project is described in the fourth section. An preliminary estimation of the sensitivity of the 50 m as a pulsar telescope is given in the fifth section. The last section contains some concluding remarks.

2 THE MIYUN STATION

The Miyun Station was founded in 1960s. The geographical coordinates of the station are: longitude 116° East, latitude $40^\circ 30'$ North. The altitude of the station is about 155 m above sea level. The station was located to the north of the Miyun reservoir. The reservoir, the station and some nearby villages were surrounded by mountains. These mountains provide good natual local shielding to the RFI from outside.

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Table 1 The Main Specifications of the Miyun 50 m Antenna

Items	Specifications
Dish Diameter	50 m
Mounting	Azimuth-Zenith
Surface (< 30 m)	solid aluminium panel
Surface (30–50 m)	stainless steel welded wire mesh
Surface r.m.s (< 30 m)	1.0 mm
Surface r.m.s (30–50 m)	3.0 mm
Pointing accuracy	$19''$
Slew rate (zenith)	$0.5^\circ \mathrm{s}^{-1}$
Slew rate (azimuth)	$1.0^\circ \mathrm{s}^{-1}$
Optics	Prime focus, f/D=0.35

The main instrument at the Miyun station is the Miyun Synthesis Radio Telescope (MSRT). It is an east-west earth-rotation synthesis array. It consists of 28 elements, each of which is a 9 m dish. The east-west baseline is about 1164 meters long. The MSRT started routine operation in 1985. The main output of MSRT is the 232 MHz northern sky survey (Zhang et al. 1997). In addition to the survey, the MSRT also carried out other observations, such as Supernova Remnant (SNR) and Interplanetary Scintillation (IPS) observations (Wu et al. 2001).

In 1990, a 15 m antenna was built at the Miyun Station. The first pulsar observation in China was carried out on it (Kang et al. 1992). This 15 m telescope has now been removed, and the new 50 m is now being built in its place.

Now the new Miyun 50 m telescope is under construction. A new observing building and living facilities will be built soon. The Miyun Station is going to serve both the Chinese lunar mission and radio astronomy in the near future.

3 THE 50 M RADIO TELESCOPE

3.1 The Main Specifications and the Current Status of the Construction

The Miyun 50 m antenna is a wheel-on-track system. It adopts an Azimuth-Zenith mounting like most of the other large radio antennas in the world. Initially, we will only use the prime focus. The main reflector is made from two kinds of panels: solid aluminium plate and stainless steel welded wire mesh. The central 30 m aperture is filled with solid panels, and wire mesh is used for the outer part. The main specifications of the antenna is listed in Table 1.

The technical design of the 50 m telescope was started at the end of 2002. The prospection for the foundations was done in 2003 (see Figure 1). The on-site assembly was carried out in 2004. The main reflector with it's backing structure was assembled separately on the ground. It was hoisted onto the pedestal on 2005 October 20 (see Figure 2). The assembly is almost finished now.

3.2 A Possible Upgrading Plan

In addition to being a ground station, the 50 m telescope will also join the VLBI network for precise tracking of the lunar orbiter. The 50 m is potentially a good element for the future VLBI network, mainly due to its geographical location. The current highest frequency planned is 15 GHz for which the central 30 m will be used. This may limit its usage in VLBI observations.

We have been thinking the possibility of using active panels to reach a higher frequency regime. A higher frequency 50 m telescope would not only allow it to participate most of the current VLBI observations, but also enhance its ability in single dish observations.

Finite element analysis was employed to inspect carefully the structure of the main reflector and the pedestal. It was shown that the structure is strong enough to support additional weight loads, such as actuators, panels, etc. By using active reflector panels, the central 30 m of the main reflector may work up to 43 GHz.

Further design work is needed for this possible upgrade. Finer adjustment in positioning the receiver within the focus cabin may be needed. Furthermore, the track and the elevation bearing may need to be

Fig. 1 The picture shows the prospecting apparatus on the site. Some samples of the rocks underground is shown at the bottom right corner. Photo taken in 2003.

Fig. 2 The picture shows the hoisting of the main reflector onto the pedestal. The main reflector was hoisted in one piece. Photo taken in 2005.

inspected carefully due to the higher pointing precision that would be required for higher frequency operations. These are yet to be investigated.

4 THE L-BAND PULSAR RECEIVER

The main scientific motive of building a 50 m dedicated pulsar radio telescope is to carry out long term monitoring of a group of known millisecond pulsars. There are three main objectives: gravitational wave background detection using precise Time of Arrival (ToA) measurement; pulsar astrophysics; a timing standard based on the ToA measurements.

Fig. 3 This picture shows the dewar and the rotatory pump.

We proposed to build an L-band pulsar receiver for the Miyun 50 m telescope. This project was approved in 2003 by CAS as one of the key projects of the KIP program. This is a three-year project. The pulsar receiver is scheduled to be built by the end of 2006.

The nominal frequency coverage of the receiver frontend is 1.2–1.8 GHz. We plan to use 300 MHz bandwidth from the above frequency range for pulsar observation. We are aiming at a system temperature of less than 30 K, and a backend which is suitable for millisecond pulsar observations.

A cryogenically cooled frontend will be built to achieve the required low system temperature. We are now working on our first test dewar system (see Fig. 4). The preliminary evacuating and cooling experiments were successful. We have achieved a vacuum level of the order of 10^{-5}Pa, and a temperature of about 20K at the secondary stage of the cold head. We will start to test the long term performance of the cooling system soon.

The backend should be able to perform the necessary de-dispersion for pulsar observations. There are at least two approaches, using incoherent and coherent de-dispersion (Hankins & Rickett 1975). In the incoherent approach, the observed band is divided into narrower channels. The received voltage signal in each channel is squared and shifted to remove the relative delay caused by the dispersion effect. The shifted data are then summed and folded to get a pulsar integrated profile. In this approach, there is residual dispersion within each channel. This will cause a time smearing within each channel. By using narrower channels, this time smearing could be smaller. But when the channel gets narrower and narrower, the time resolution is getting worse for the signal within each channel. So, there is an optimized channel width for incoherent de-dispersion for a given pulsar. This is the time resolution limit that is inherent in the incoherent approach. In the coherent de-dispersion approach, however, the dispersion effect is removed completely provided that the dispersion measure (DM) is known sufficiently accurately. In this case, the time resolution is of the order of the reciprocal of the total observing bandwidth. We simulated this effect in Figure 4.

There is no doubt that the coherent approach is perfected, but this may require large amount of computing resource. The cost of the current software-based PC-cluster coherent pulsar backend COBRA and CPSR2 system, after being scaled up to 300 MHz, will be far beyond our budget. The digital filter bank (DFB) system that is now being developed at ATNF, is able to process 1GHz bandwidth data (Manchester 2006). Though it is currently an in-coherent filterbank system, it may fit most of our needs. This may be our best choice. We have contacted the ATNF, discussing the possibility to adopt their DFB for our 50 m telescope.

5 THE 50 m AS A PULSAR RADIO TELESCOPE

The 50 m radio telescope is fully stearable. The low elevation limit is $5°$. Given the geographical location of the telescope, this will allow the telescope to cover the sky with Declination larger than $-35°$. So, the 50 m telescope will be able to observe about 60% of all the pulsars known today (Manchester et al. 2005).

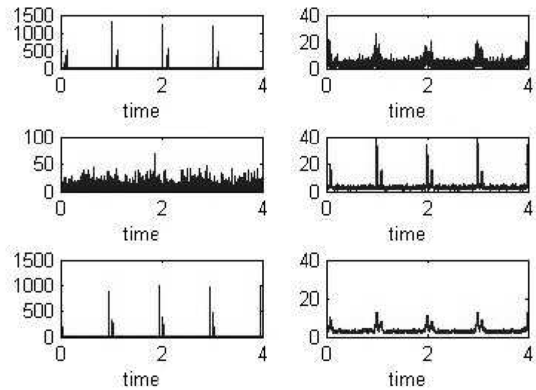

Fig. 4 This figure shows the dispersion and de-dispersion of a simulated pulsed signal. On the left column, the simulated pulsed signal, the signal after being dispersed, and the coherent de-dispersed signal are shown from top to bottom. On the right column, we show the incoherent de-dispersed signal with different numbers of channels. The top image is with small number, the middle with moderate number, the bottom with large number of channels. It is clearly seen that the coherent approach could recover the pulsed signal very well. While the time resolution of incoherent approach is optimized by a certain number of channels, and is worse than that of the coherent approach.

Being equipped with an L-band, 300 MHz pulsar receiver, assuming a system temperature of 30K. We may use the following formula to estimate the sensitivity of the telescope:

$$S_{\rm min-pulsar} = 2 \cdot \beta \cdot \frac{k \cdot T_{\rm sys}}{A_c \cdot \sqrt{2 \cdot B \cdot t}} \cdot \sqrt{\frac{w}{(p-w)}}\,. \tag{1}$$

The above formula estimates the minimum flux density of a pulsar that could be detected by the 50 m telescope. In the formula, β is the signal to noise ratio (S/N), A_c is the effective collective area of the 50 m telescope, p and w are the period and the pulse width of a pulsar. Assuming a pulse width of 0.16 relative to the pulsar period, and a S/N of 8, the flux density of the weakest detectable pulsar would be 0.065 mJy for an integration time of 10 hours. For an integration time of half an hour, this flux density would be 0.29 mJy.

6 CONCLUSIONS

The Miyun 50 m radio telescope is the largest single dish in China. It will work for the coming Chinese lunar mission and radio astronomy as well. We are building an L-band 300 MHz pulsar receiver for the 50 m telescope, so making it a powerful pulsar observing tool, to carry out pulsar observations and researches in the very near future.

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