# Introduction of Promoting Very Long Baseline Interferometry for Deep Space Tracking in China

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## Abstract

Very Long Baseline Interferometry (VLBI) has been developed in China near 30 years for astronomical studies. Since 2003, following the development of Chinese lunar and deep space exploration, the astronomical VLBI technique was adapted for tracking and orbiting the Chinese Chang'E 1 & 2 missions, and played important role on positioning the orbit injection and hard landing. Since 2007, the concepts of open loop Doppler, differential one way range (DOR) and different one way Doppler (DOD) have been accepted by Chinese VLBI system for Martian missions. It has been successfully tested when tracking the ESA MarsExpress Mission. In the near future, same beam VLBI technique will also be applied by this system for tracking dual Martian mission Phbos-Grunt and Yinghuo-1, as well as positioning the Chang'E-3/4 landers & rovers. Based on these engineering and technical developments, close collaboration with other VLBI systems and networks have been set[1-3].

## 1. Chinese VLBI network

Since early 1980s, A small team of Shanghai Astronomical Observatory of CAS started to introduce and develop VLBI in China. After successful VLBI test experiments with Japan and Germany by using a 6-meter S-Band recording system, Chinese VLBI built a 25-meter antenna at Shanghai in 1987, and a 25-meter antenna at Urumqi in 1994, working at L, S/X, C, K band. In a long history, the Chinese VLBI has been applied for the observation and study of space geodesy, radio astrometry and radio astrophysics, by join in the European VLBI Network and International VLBI Service network. Before 2000, the two antennas also took part in a few international collaborations on tracking some deep space missions, like Cassini-Huygens. A small team had also finished a pre-research of using VLBI for lunar and deep space tracking based on a Ph.D research program of 1st author.

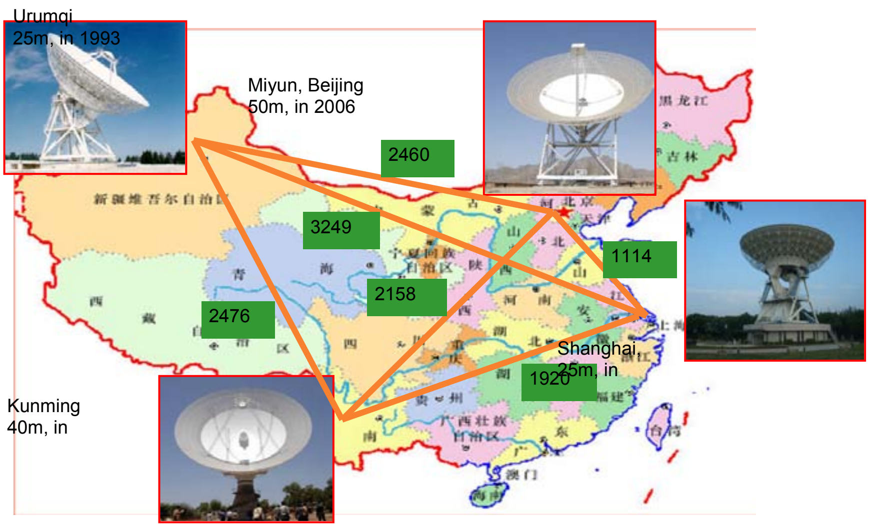


**Figure 1. Distribution of Current Chinese Astronomical VLBI Network**

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In 2001, Chinese government started to promote and prepare the 1st Chinese lunar orbiter mission. From then on, one of the key problems, radio tracking ability between the Earth and the Moon started to draw attention of engineers and scientists. From 2003, the Chinese VLBI researchers started to develop Chang'E lunar mission VLBI tracking system. Two new VLBI antennas were constructed in 2006 working at S/X bands for also geodetic and astronomical observations, where 50-meterVLBI antenna at Beijing, 40-meter antenna at Kunming. Also, a new VLBI data analysis center with hardware and software correlators was set up at Shanghai Astronomical Observatory. Currently, the network is composed of 4 stations located at Beijing, Shanghai, Kunming and Urumqi, see Figure 1. The network can do radio observation at L/S/C/X/Ku band. The S/X dual-frequency mode covers the whole band for ITU satellite communication, it can satisfy the observation requirement of Geodesy and satellite tracking.

## 2. Chinese VLBI network for lunar orbiters

Since year 2003 the start of Chinese lunar mission Chang'E-1, the Chinese VLBI network system has been playing important roles in both of astronomical observation and lunar/planetary deep space tracking. Since 1990s, this network has taken part in some international s/c VLBI tracking work, and some domestic s/c tracking work. For example, it has support the missions of CASSINI-HUYGENS, Planet-B, SMART-1, Mars Global Survey, SELENE, Double-Star, Chang'E-1. In two recent lunar mission, the SELENE and Chinag'E-1 mission, this network realized the real-time s/c tracking and POD by VLBI method. Using its data together with unified S-Band tracking data, the lunar gravity field can be improved by either the common or the SBI VLBI mode.

To prepare the tracking of Chang'E series missions, Chinese VLBI network accomplished its whole system in 2006, and carried out dozen experiments of tracking the ESA SMART-1 lunar mission with support from SMART-1 tracking team. After removing the systematical errors of instruments and media, a delay error rms of 4~5 nano seconds was obtained in all baselines, see figure 2.

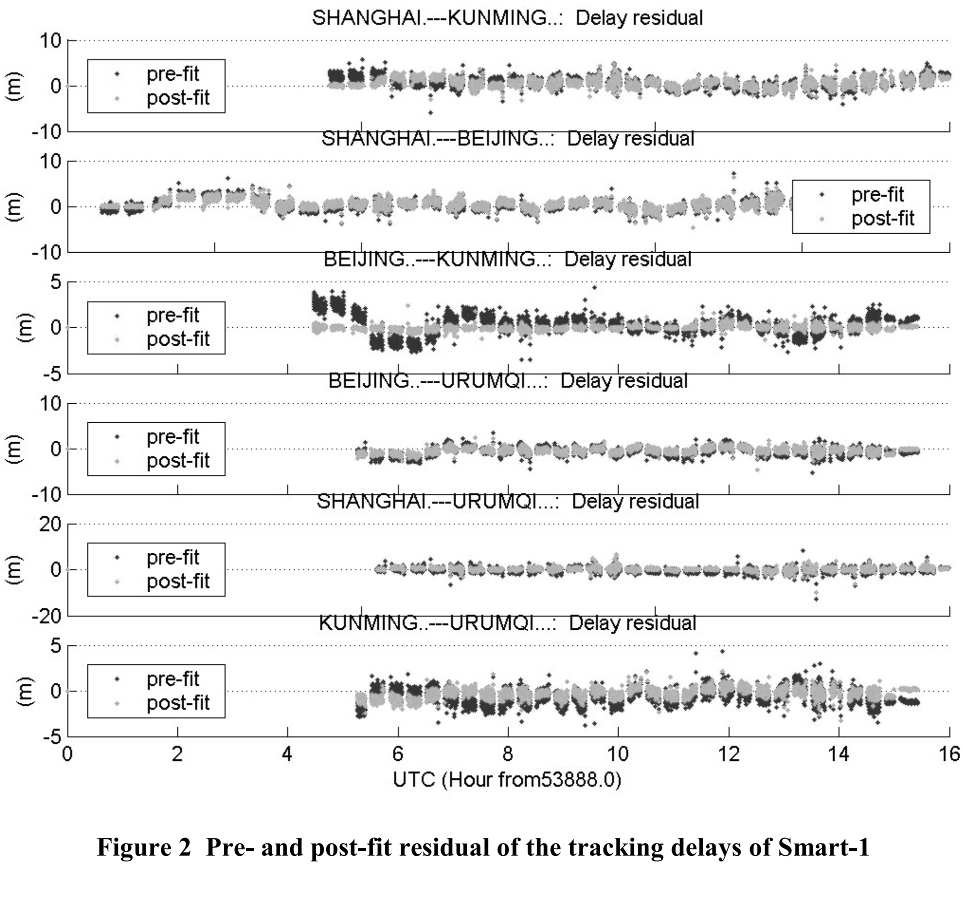


**Figure 2 Pre- and post-fit residual of the tracking delays of Smart-1**

Using above method, the Chinese VLBI tracked all flying mission of Chang'E-1, including hard landing. Based on the tracking observations of radio ranges and VLBI delays of Chang'E-1 (CE-1) satellite during the controlled landing on the Moon on March 1, 2009, the landing trajectory and the coordinates of the landing point are determined by positioning analysis. It is shown that the landing epoch (the emission epoch of the last signal) of CE-1 satellite on the

Moon was at UTC8h13m6.51s. The lunar longitude, latitude and surface height of the landing point in the lunar primary axes frame are respectively 52.2732 deg, 1.6440 deg and -3.56 km (The reference lunar radius is 1738 km.). The uncertainties are 0.0040 deg, 0.0168 deg and 0.18 km. The corresponding uncertainty in the tangential direction of the lunar surface is 0.52 km and the three-dimensional (3D) positioning uncertainty is 0.55 km. It is accordingly deduced that even with the present technical specifications of the radio ranges and VLBI delays, the 1 km 3D positioning precision could be guaranteed for the lander in the second stage of China's Lunar Exploration Project. Concerning the trace determination of the rover on the lunar surface, because only telemetry signal will be emitted, VLBI would be the sole tracking technique from the Earth.

Also, the same-beam VLBI observations of Rstar and Vstar, which were two small satellites of Japanese lunar mission, SELENE, were successfully performed by using Shanghai and Urumqi 25-m telescopes. When the separation angle between Rstar and Vstar was less than 0.1 deg, the differential phase delay of the X-band signals between Rstar and Vstar on Shanghai-Urumqi baseline was obtained with a very small error of 0.15 mm rms, which was reduced by 1–2 order compared with the former VLBI results. When the separation angle was less than 0.56 deg, the differential phase delay of the S-band signals was also obtained with a very small error of several mm rms. The orbit determination for Rstar and Vstar was performed, and the accuracy was improved to a level of several meters by using VLBI and Doppler data. For tracking lander and rover, It is worthy to pay close attention to the applications of the same beam VLBI technique, the lunar topographic model and the on-board observations of the lander and rover to the position/trace determination of the rover.

## 3. Chinese VLBI network for Martian orbiters

Since 2007, the concepts of open loop Doppler, differential one way range (DOR) and different one way Doppler (DOD) have been accepted by Chinese VLBI system for Martian missions. It has been successfully tested when tracking the ESA MarsExpress Mission. In the near future, same beam VLBI technique will also be applied by this system for tracking dual Martian mission Phbos-Grunt and Yinghuo-1, as well as positioning the Chang'E-3//4 landers & rovers. Based on these engineering and technical developments, close collaboration with other VLBI systems and networks have been set. The Delta-VLBI for S/C tracking is shown in Figure 3.

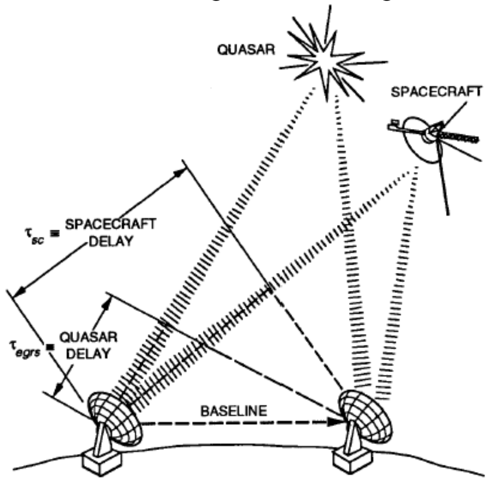


**Figure3 The Concept Diagram of Delta-VLBI**

The "Chinese-Russian collaborative Mission for Mars" is planned in the government level, and the final agreement has been signed in 2007. The two probes will be launched together in November, 2011. Lavochkin Association and IKI of Russia side will be responsible for developing the FGSC; Shanghai Academy of Spaceflight Technology and CSSAR/CAS will be responsible for developing the YH-1 mission. They will coordinate the issues of joint launching and joint exploration. After a successful launching, the joint spacecraft YH-1 & FGSC will be sent to a transfer orbit flying to the Mars. After 10-11months, the joint craft will arrive the Martian system, and will be eject into an equatorial orbit of 800x80000km, with a period of ~72hours, inclination of $26^{O}$. The joint craft will fly in this orbit for about 3 circles, then they will be separated, FGSC will change its orbit to find change of landing on Phobos, and YH-1 will free-fly in this orbit for 1year.

The high-accuracy same-beam differential VLBI technique is very useful in orbit determination for a spacecraft, and will be used in orbit determination for Mars missions of China Yinghuo-1 and Russia Phobos-grunt. The tracking stations and the VLBI center are connected by Intelnet. In SELENE mission, the observation data can be sent to National Astronomical Observatory of Japan by using TCP/IP ftp data transferring mode. In Chang'E-1 mission, the VLBI tracking data can be sent to the Shanghai VLBI center using real-time IP data stream mode, to carry out real-time correlation. In YH-1 mission, the network will be slightly enhanced by including 2-3 Russian VLBI stations. After getting the VLBI observable, the VLBI center will also do the S/C orbit estimation and prediction for mission users.

In Yinghuo-1 mission, one-way Doppler will play key role in orbiter determination tracking. We developed digital Doppler card using software radio method, and integrated the Doppler, radio science receiver, VLBI recording system into one system. This RSR/VLBI system are connected with the VLBI IF.

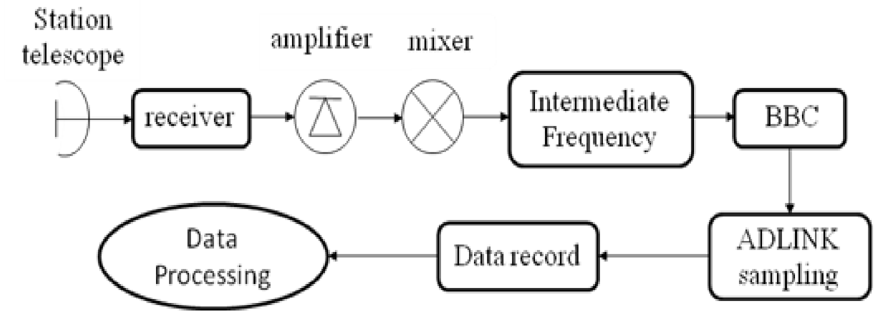


**Figure 4. A simple flow chart for a open-loop Doppler data processing system**

For above target, A prototype based on digital radio technology with associated open-loop Doppler signal processing techniques has been developed to measure a spacecraft's line-of-sight velocity, see Fig 4. It was tested in Chang'E-1 lunar mission with results of a RMS value of ~3 mm/s (1 $\sigma$ ) using 1-sec integration at s-band. Such precision is mainly limited by the short-term stability of the atomic (e.g. rubidium) clock at the uplink ground station. It can also be improved with proper calibration to remove some effects of the transmission media (such as solar plasma, troposphere and ionosphere), and a longer integration time (e.g. down to 0.56 mm/s at 34 seconds) allowed by the spacecraft dynamics. The tracking accuracy has been increased during the test observation of Mars Express VLBI experiments, with RMS of 0.3mm/s. Our experimental tracking data have been used in orbit determination for Chang'E-1 and Mars Express. This method will benefit such as the upcoming YH-1 Mars orbiter.

## 4. Future development of Chinese VLBI network in deep space

Following the development of VLBI in deep space tracking, Chinese VLBI network will find chance in two directions in this field, 1st , updating and using astronomical VLBI system in s/c tracking and positioning, by taking the advantage of e-VLBI and geodetic VLBI, 2nd , accepting the DOR standard and join in Chinese deep space tracking network, which will be accomplished in a few years. The developing work in the 1st direction has almost been carried out, and been using in Chang'E series mission. Currently, researchers and engineers are developing DOR/DOD and differential phase method following the 2nd direction. This work is estimated be accomplished and applied in 3~5 years.

## Acknowledge

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