Shanghai VLBI Correlator

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Abstract This report summarizes the activities of the Shanghai VLBI Correlator during 2014. Highlights include the commissioning of DiFX correlation, fringe tests for Tianma65, e-VLBI connection with international stations, and validation of 512 MHz bandwidth observations.

1 Introduction

The Shanghai VLBI Correlator is hosted and operated by the Shanghai Astronomical Observatory (SHAO), Chinese Academy of Sciences. It is located on the Sheshan campus, about 40 kilometers from the Xujiahui headquarters of SHAO. The Shanghai correlator plays a leading role in the data processing of the Chinese domestic VLBI observing programs, inclusive of the CMONOC project for monitoring the Chinese regional crustal movement, and the Chinese deep space exploration project for spacecraft tracking.

As shown in Figure 1, Shanghai (including Seshan25 and Tianma65), Kunming, and Urumqi participate in some domestic geodetic and astronomical sessions, while the Beijing station is mainly used for spacecraft data downlink and VLBI tracking. A few joint observations with the Chinese deep space stations Kashi and Jiamus were also performed.

In order to contribute more to the international VLBI community and to meet the requirements of more domestic astronomical VLBI experiments, we imported the DiFX correlator in recent years. The Shanghai correlator was accepted as an IVS correlator in March 2012. It will become operational for IVS data correlation in 2015.

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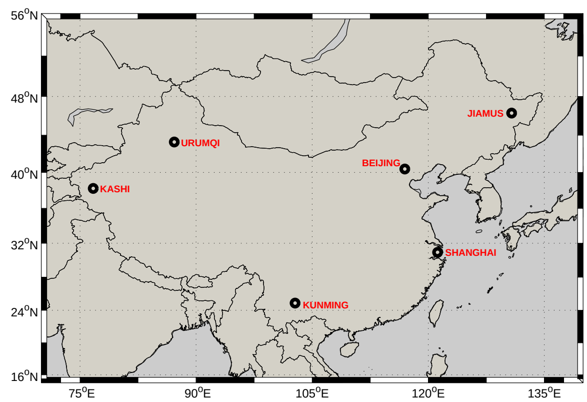

Fig. 1 Distribution of the VLBI stations in China.

2 Component Description

We are operating two types of correlators. The correlator developed by our own staff has been operational since 2006. It is mainly used for spacecraft VLBI tracking in the Chang'E lunar exploration project by producing differential VLBI observables. The data latency is less than one minute in real time mode, and the typical accuracy is better than 1 ns. It is also used to correlate a few tens of CMONOC geodetic sessions by producing NGS card files which will be made public very soon. The other correlator is the DiFX correlator, which is dedicated to astrophysical and geodetic data correlation.

By the end of 2014, the former 60 core DiFX platform was expanded to a 420 core cluster system (Figure 2). The storage space was also increased to 430 TB. The new platform is very important for IVS data correlation. In the routine operations, half of the computing and the storage sources are assigned to the geodetic correlation tasks. Features of the DiFX cluster system are listed as follows:

- DiFX 2.2/2.3/trunk, HOPS 3.9/3.10
- Head nodes: DELL R820 (E5-4610 CPU, 2.4 GHz, 2*6 cores), 64 GB Memory, DELL R730 (E5-2623 CPU, 3.0 GHz, 2*4 cores), 64 GB Memory.
- Computing nodes: 20 DELL R630 nodes, two socket Intel E5-2660 CPU (2.6 GHz, ten cores), 64 GB Memory, 400 cores in total
- I/O nodes: RAID6, 432 TB raw storage capacity
- Mark 5 units: three Mark 5A and three Mark 5B.
- 56 G Infiniband for internal computing network connection
- 1/10 G Ethernet for internal and external network connection

Fig. 2 DiFX cluster system and Mark 5A/B units.

3 Staff

The people involved in the development and operation of the Shanghai Correlator are listed below.

- Weimin Zheng: group head, software correlator development
- Xiuzhong Zhang: CDAS and other technique development
- Fengchun Shu: scheduler, experiment oversight, CDAS evaluation
- Zhong Chen: e-VLBI, cluster administration
- Wu Jiang: DiFX operation, experiment support
- Tianyu Jiang: DiFX operation, experiment support
- Weihua Wang: lead correlator operator, automatic correlation process development
- Wenbin Wang: operator, experiment support
- Zhaobao Jiang: media library, computer services
- Renjie Zhu: CDAS development
- Zhijun Xu: FPGA programming, hardware correlator development
- Yajun Wu: FPGA programming
- Juan Zhang: correlator software development and maintenance
- Li Tong: correlator software development and maintenance
- Lei Liu: post-doctoral fellow, correlator software development

4 Summary of Activities

4.1 DiFX Correlation

With the help of the Bonn Correlator and the GSFC group, we have obtained some experience in using DiFX, HOPS, and Dbedit to generate Mark IV database files. As mentioned above, a new DiFX cluster system was installed and tested in December 2014 in preparation for IVS data correlation.

In order to make the correlation results reliable, we also made a comparison with Bonn on the four-station (NyShTsWz) INT3 session K14349. Although the two correlators used different parameter configurations, the total delay observables can be used for comparisons. The database generated by the Shanghai Correlator has been analyzed with nuSolve by Minghui Xu. Some data solution statistics for comparison against the IVS result[1] can be found in Table 1. Our results have an additional bad point 2014-12-15 UT 7h12m49s on

[1] Please see `http://lupus.gsfc.nasa.gov/data10/sessions/2014/k14349/k14349-analyst.txt`

NYALES20-SESHAN25. We suspect we lost a little data from Seshan25 when copying from the original Mark 5 module. We compared 141 common points used in the solutions. The mean value of the X-band group delay differences is 0.9 ps, and the RMS is 9 ps, while the mean value of the S-band group delay differences is 10.7 ps, and the RMS is 58 ps. The comparsion shows that there are two points with group delay differences greater than 20 ps at X-band and five points with differences greater than 100 ps at S-band. As shown in Figure 3, we plotted the histogram after the removal of the seven points with big differences mentioned above.

Table 1 Statistics on UT1 solutions with data from the Bonn and the Shanghai correlators.

	Bonn	Shanghai
Number of observations scheduled	180	180
Number of observations correlated	169	169
Number of observations used	142	141
WRMS delay residual (ps)	42.7	41.6
UT1 formal error (μs)	8.87	8.99

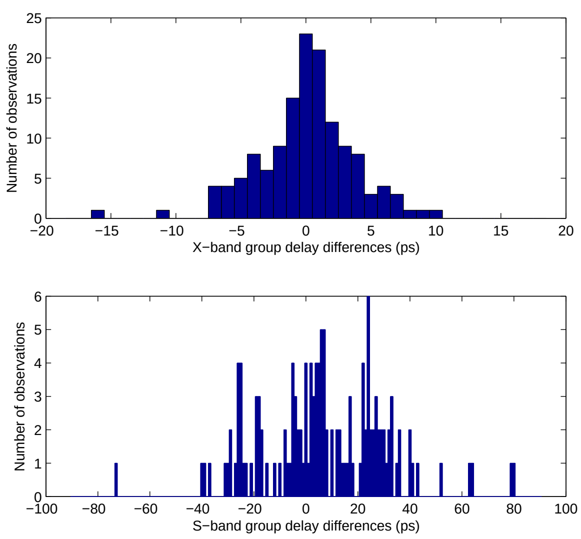

Fig. 3 Histogram for group delay differences produced by the Bonn and the Shanghai correlators.

4.2 Fringe Tests for Tianma65

In order to bring Tianma65 online for VLBI astrometry, we have been conducting a series of fringe tests since 2013. We finally received good fringes for a standard wideband S/X sequence on the Tianma65-Seshan25 baseline on March 24. As a result, Tianma65 participated in R1637 in May and in RD1404 in June. With its high sensitivity, Tianma65 is able to improve the total observations of an array and the detection of weak sources, which is important for radio-optical frame connection and densification of the ICRF.

4.3 e-VLBI

The network link to Seshan25 and Tianma65 is 10 Gbps. The network link to the Urumqi, Kunming, and Beijing stations is 155 Mbps for domestic e-VLBI observations. In the Chang’E-5T1 lunar mission beginning in October 2014, the data transfer performed well at 64 Mbps for each station.

In order to process IVS global sessions in 2015, we established the network link to Kashima, Sejong, Hobart, Noto, HartRAO, Fortaleza, and the Bonn Correlator. The maximum data rate is 1 Gbps. More stations involved in the CRF and APSG sessions will be connected to Shanghai.

4.4 Performance of CDAS

The Chinese VLBI Data Acquisition System (CDAS) is a type of digital backend designed to replace the traditional analog BBCs. The new digital system has better bandpass and wider bandwidth. In 2014, we successfully upgraded the CDAS at Kunming, so it can now observe standard wideband S/X sequences such as in CRF and R&D sessions.

In addition to the DDC version currently being used, we are also developing a PFB version of CDAS with much more of a compact design. It contains two Xilinx K7 FPGAs for data processing. The input signals are from two IFs with 512 MHz bandwidth each or one IF with 1024 MHz bandwidth. Compared with the previous platform, which consists of four Xilinx V4 FPGAs, the new one not only updated the key chips for

DSP but also added two TenGiga Ethernet SFP+ ports for data transmission. For the application, the PFB version can be configured with 32 MHz bandwidth x 16 channels and 64 MHz bandwidth x 16 channels.

4.5 Development of Correlator Technique

Aimed at the parallel data processing of two spacecraft in the Chang'E-5 mission, which was scheduled to be launched in 2017, our own real time correlator systems are undergoing a major upgrade.

4.6 VEPS

The VEPS (VLBI Ecliptic Plane Survey) project submitted to the NSFC (Natural Science Foundation of China) has been funded with a four-year term from 2014 to 2017. In the first phase we planned to observe approximately 2,000 radio sources along the ecliptic with the total flux greater than 0.1 Jy by VLBI for the first time. The 512 MHz bandwidth observing mode with 32 MHz bandwidth x 16 channels at wide X-band can be provided by CDAS and K5 backend. The fringes have been obtained with Seshan25, Kunming, Urumqi, Tianma65, and Sejong. The last two stations will be backup stations for VEPS.

4.7 Experiments Correlated

In 2014, only two domestic geodetic VLBI experiments were carried out due to limited available time of Urumqi and the launch of the Chang'E-5T1 mission. After the Mark 5 modules were shipped to Shanghai, the data correlations were done by both the domestic correlator and the DiFX correlator. The output of the DiFX correlator was further processed with HOPS.

The differential VLBI observations were conducted frequently to support the navigation of the Chang'E-5T1 spacecraft from October 24. The signals transmitted from the spacecraft were received by four Chinese stations and then transferred to Shanghai in e-VLBI mode for data correlation and the extraction of differential VLBI observables within one minute.

4.8 Phase-referencing of Spacecrafts

We have developed offline software to convert our own correlator output into FITS-IDI format since 2013. Based on this type of data, we try to do relative positioning between the rover and lander of Chang'E-3 on the surface of the Moon by using the phase-referencing method, and we get accuracy at the level of a meter. Now, we are trying to do spacecraft positioning (CE-5T1, MEX, et al.) with respect to the extragalactic radio sources by using the phase-referencing method, and we have gotten some preliminary results.

4.9 IVS GM2014

The eighth IVS General Meeting was held March 2-7, 2014 in Shanghai, China. The keynote of the eighth General Meeting is the establishment of the VGOS (VLBI Global Observing System) network under the theme "VGOS: The New VLBI Network". Fengchun Shu served as a member of the program committee, and Weimin Zheng served as the chair of the local organizing committee. During the meeting, an excursion was arranged to visit the VLBI data processing center equipped with the correlator, the Tianma Radio Telescope, the Sheshan 25-m antenna, and the Shanghai Astronomical Museum. The local organizing work was basically done by our group.

5 Future Plans

We will begin to correlate a few international VLBI sessions coordinated by the IVS in 2015 and we will ensure that the final results are reliable and convinced by making comparisons with other IVS correlators. We will continue to support the data correlation of the Chinese domestic VLBI observations. Considering that we have already submitted a correlator upgrade proposal for VGOS correlation, we are also interested in getting some real VGOS data for trial correlation.