Correlation Processing of VLBI Observations of GEOTAIL Sattellite Using K4 and IP-VLBI System

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Delta VLBI test observations of GEOTAIL were carried out using the IP-VLBI system in collaboration with the Institute of Space and Astronautical Science of Japan (ISAS) and the National Astronomical Observatory of Japan (NAO) to check automatic observation software and to evaluate the accuracy of observed delay obtained by the IP-VLBI system. Results are reported.

GEOTAIL相対VLBI実験観測の相関処理結果　-K4及びIP-VLBIシステム-

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通信総合研究所では相対ＶＬＢＩ観測による宇宙飛翔体軌道決定技術に関する研究を進めている。実際に衛星からの信号を使って自動観測システムおよび相関処理システムを評価するために、現用のＫ４ＶＬＢＩシステムおよび開発中のインターネットＶＬＢＩシステムを使用して、「ＧＥＯＴＡＩＬ」衛星の相対ＶＬＢＩ試験観測を宇宙研と共同で実施した。その結果について報告する。

1 Introduction

Communications Research Laboratory has promoted a research on the spacecraft positioning technology by using a delta VLBI technique. A general-purpose VLBI system using the Internet and a personal computer has been developed as a part of this project and it is called an IP-VLBI system[1][2] or a VSSP system[3]. The IP-VLBI system aims at a real-time VLBI system, and off-line observations and correlation processing are possible at present. Delta VLBI test observations of GEOTAIL satellite[4] were carried out using the IP-VLBI system in collaboration with the Institute of Space and Astronautical Science of Japan (ISAS) and the National Astronomical Observatory of Japan (NAO)

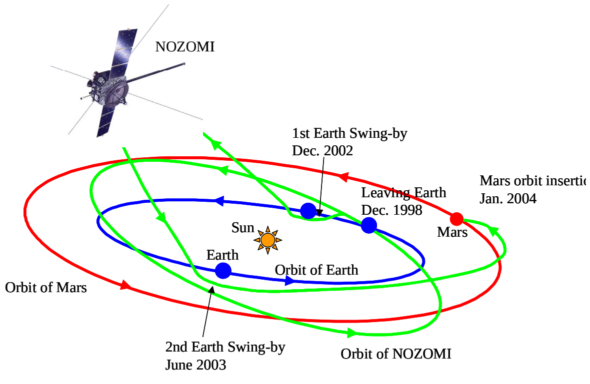

Fig.1 Trajectory of NOZOMI (after http://www.isas.ac.jp/e/enterp/missions/nozomi/traject.html).

to check automatic observation software and to

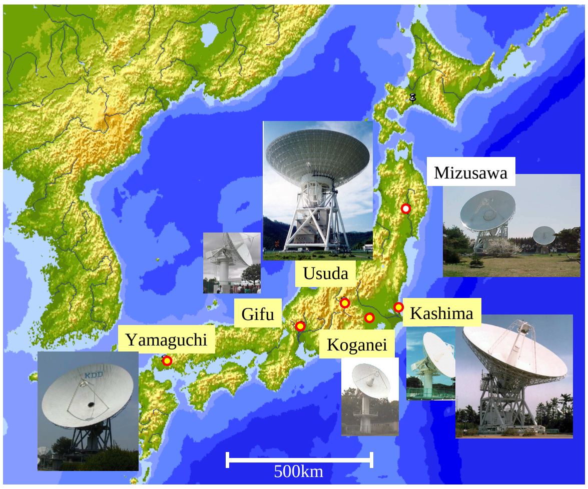

Fig.2 The location of stations participated in GEOTAI VLBI observations

Table 1 GEOTAIL test observation schedule

Date YYYY/MM/DD	Time(UT)	Stations (name with a diameter in meter)
2002/06/04	06:49-14:00	Usuda64 Kashima34 Kashima11 Mizusawa10*1 Yamaguchi32*2
2002/06/25	08:30-14:38	Kashima34 Kashima11 Koganei11
2002/06/28	01:58-03:00	Kashima34 Kashima11 Koganei11
2002/07/20	01:05-04:16	Kashima11 Koganei11 Gifu11

*1: unable to observe due to a thunderbolt damage
*2: undetected correlation due to a clock problem

evaluate the accuracy of observed delay obtained by the IP-VLBI system. We intend to utilize the delta VLBI observation data for the orbit-determination of NOZOMI (PLANET-B), which is a Japanese spacecraft launched in 1998 to explore Mars[5], during the period just before the last earth swing-by planned in June 2003 toward Mars.

2 Necessity of Delta-VLBI

The NOZOMI is the first Japanese Mars orbiter, and was launched on July 4, 1998. It was planned to arrive Mars in 1999 by using two-times lunar swing-bys and a powered earth swing-by. However due to malfunction of a thruster valve during the powered earth swing-by and maneuvers to recover the right trajectory to Mars, enough fuel is not left to inject NOZOMI into a Mars orbit. The NOZOMI team found a new trajectory to Mars available to

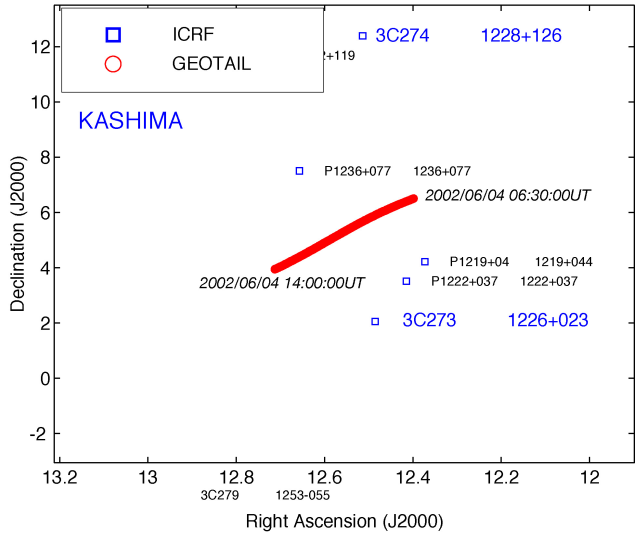

Fig.3 The position of GEOTAIL on the equatorial coordinates on June 4, 2002.

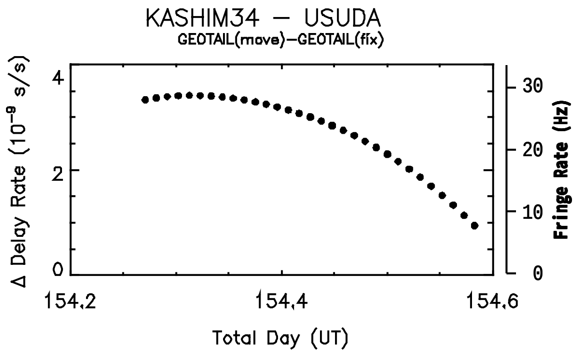

Fig.4 The difference of delay rates between that calculated for the position of GEOATIL fixed at the middle of each scan (i.e., only diurnal motion is considered) and that calculated taking the motion in the equatorial coordinates into account

inject NOZOMI into a Mars orbit. Hence the orbit insertion scheduled in 1999 was abandoned, and it is now scheduled early in 2004 after two more earth swing-bys (Fig.1). The determination of spacecraft position is usually made on the basis of range and range rate measurements using a telemetry link. However range measurement is supposed to be difficult during several months before the last earth swing-by planned on June 19, 2003 to cruise to Mars, due to a bad geometrical relation between spacecraft attitude and earth position, i.e., the high-gain antenna of NOZOMI does not point the Earth during this period. However it is very important to navigate the NOZOMI precisely during this period to succeed in the last earth swing-by. CRL and ISAS started collaboration to determine NOZOMI orbit using a delta VLBI technique and to lead a NOZOMI mission to a success [6].

A test VLBI observation was planned in June 2002 at first. Unfortunately NOZOMI had some problems at that time caused by the large solar flare

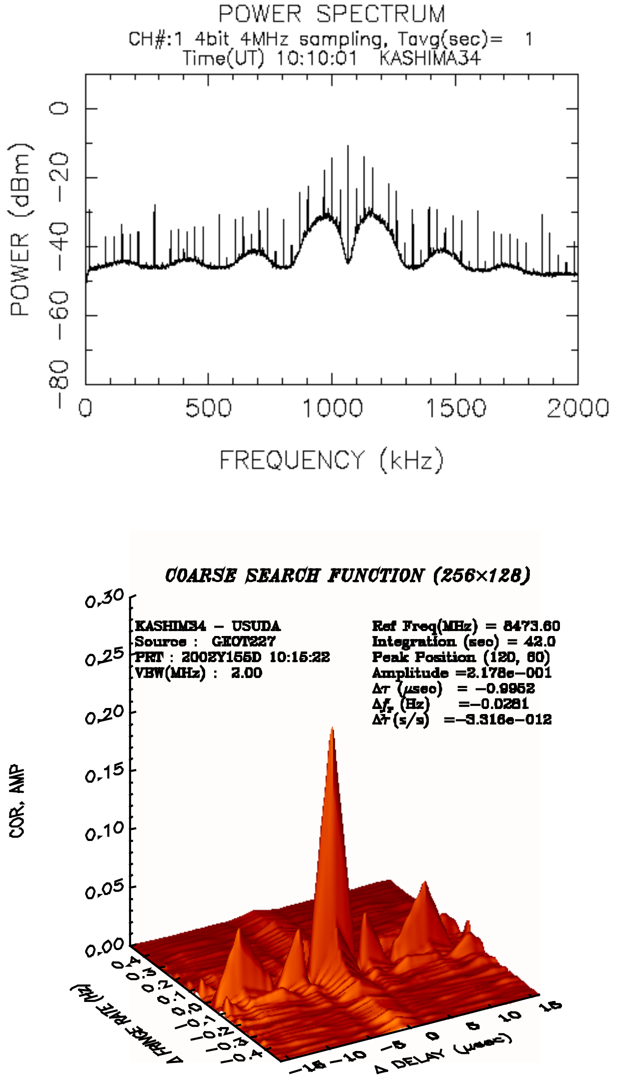

Fig. 5 A spectrum of X-band telemetry signals from GEOTAIL observed at Kashima34 (upper panel) and coarse delay search function calculated from correlated data on Kashima34-Usuda64 baseline (lower panel). Observation date is June 4, 2002.

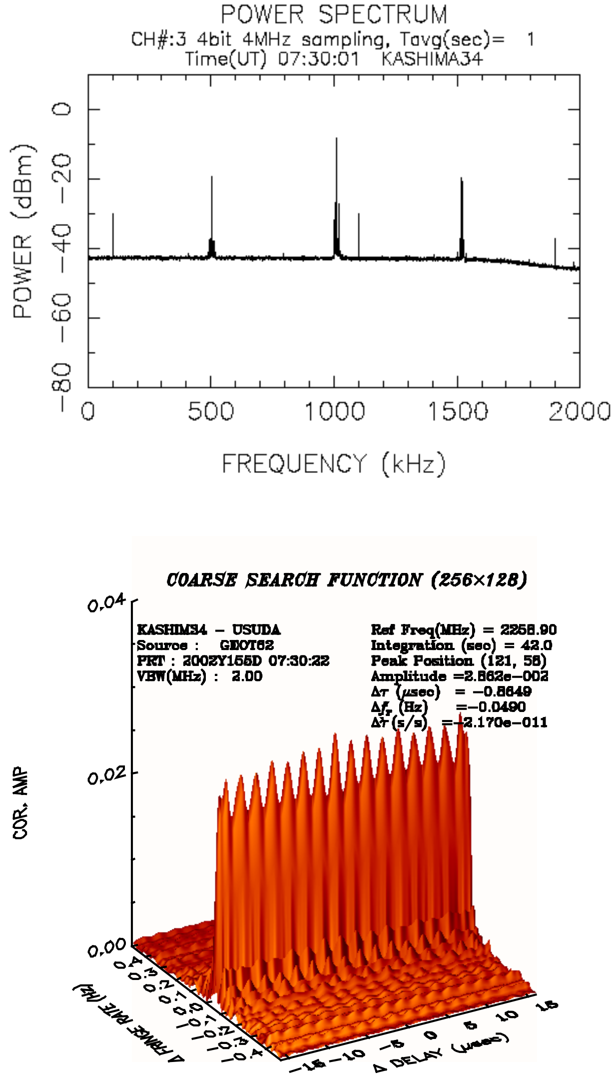

Fig.6 A spectrum of S-band telemetry signals from GEOTAIL in a range measurement mode observed at Kashima34 (upper panel) and coarse delay search function calculated from correlated data on Kashima34-Usuda64 baseline (lower panel) observed on June 4, 2002. Two micro sec ambiguities arising from 500 kHz spacing between carrier and sub-carrier frequencies can be seen in the coarse delay search plot.

occurred on April 21, 2002. Thus we had carried out a series of test VLBI observations using GEOTAIL instead of NOZOMI until it was recovered .

3 GEOTAIL Observations

VLBI observations were carried out for GEOTAIL to learn the characteristics of telemetry down-link signals and to investigate the feasibility of group delay measurements. We made observations using the IP-VLBI system. Test observations were conducted several times (see Table 1) and data reduction software was developed for a preliminary analysis. Two of four-channel inputs of the IP-VLBI system are used for S and X band signals of which base band signal frequencies are 2258.90 MHz and 8473.60 MHz, respectively. Observations were made with a sampling frequency of 4 MHz and an A/D resolution of 4 bits. The location of stations participated in the observations is shown in Fig.2.

The GEOTAIL moves so fast in the sky (see Fig.3) that a priori values calculated by using software developed for geodetic processing have insufficient accuracy, in particular in delay rate that is necessary for fringe stopping, so that we developed new a-priori calculation software for correlation processing, in which the motion of GEOTAIL is interpolated by using a spline interpolation method. Fig.4 shows the difference between delay rate calculated using the conventional a priori calculation software and that using the newly developed software. In a former calculation the position of GEOATIL in the

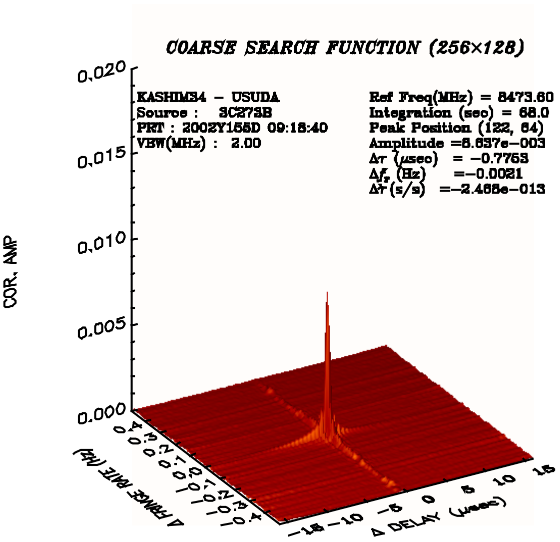

Fig.7 An example of X-band coarse search functions for a quasar (3C273B) on Kashima34-Usuda64 baseline. Observation date is June 4, 2002.

equatorial coordinates is fixed at the middle point of each scan, while actual motion in the celestial position is considered in a latter one. Maximum discrepancy reaches about 3.5×10^9 s/s in this case. It corresponds to 28 Hz fringe frequency at 8 GHz, and this will result in loss of correlation amplitude for 1 sec integration period, which is typical period for a conventional correlator. Correlation processing is carried out by software able to run at any PC without any dedicated hardware for correlation processing.

A spectrum at X-band telemetry signals and coarse delay search function calculated from correlated data are shown in Fig.5. As shown in the figure, group delay can be obtained without any ambiguities. Fig.6 shows an S-band power spectrum and coarse delay search function when telemetry mode is in a range measurement mode. In this case 2 μ sec ambiguities appeared in the delay direction. Fig.7 is an example of coarse delay search function for a quasar (3C273B).

A closure delay test was carried out to check the accuracy of observed group delays. It is confirmed that an rms error of a few nsec was attained with coarse delay measurements (Fig.8).

4 Conclusions

We have carried out a series of delta-VLBI observations of GEOTAIL using IP-VLBI system for several months to learn characteristics of satellite downlink signals and to investigate the feasibility of delay measurements. Preliminary results show that most of the cases we can determine group delays for telemetry signals without any severe ambiguities. Now an attempt to reflect VLBI data to an orbit determination is carried out by an ISAS team. Delta VLBI observations will be performed several months before the last earth swing-by scheduled on June 19, 2003 to determine orbit and to lead a Mars exploring project to a success.

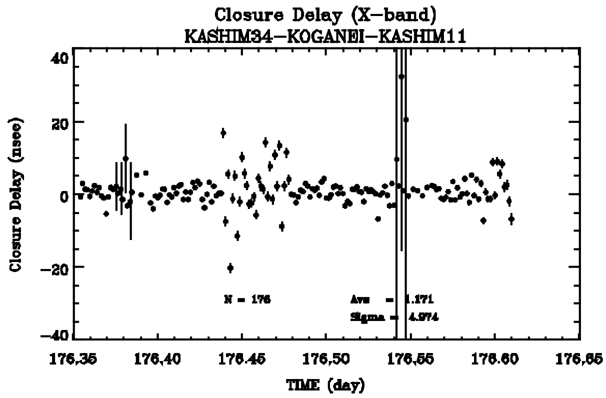

Fig.8 An example of closure delay test for GEOTAIL observations. Observations were carried out on June 25, 2002 at three stations, Kashima34, Kashima11, and Koganei11. Data with large error bars represent quasar observations. Although data are largely scattered around 176.45 days, standard deviation of total data is well less than 10 nsec.

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