Orbit Determination of The NOZOMI Spacecraft using Differential VLBI Technique

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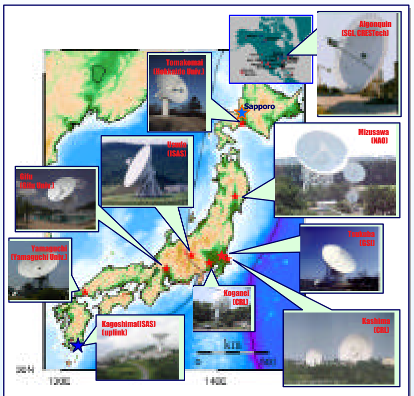
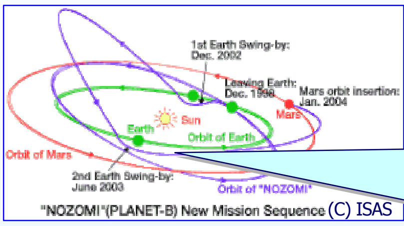
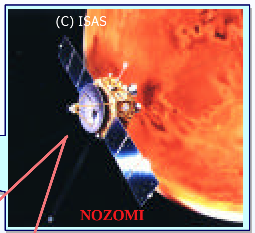
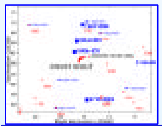


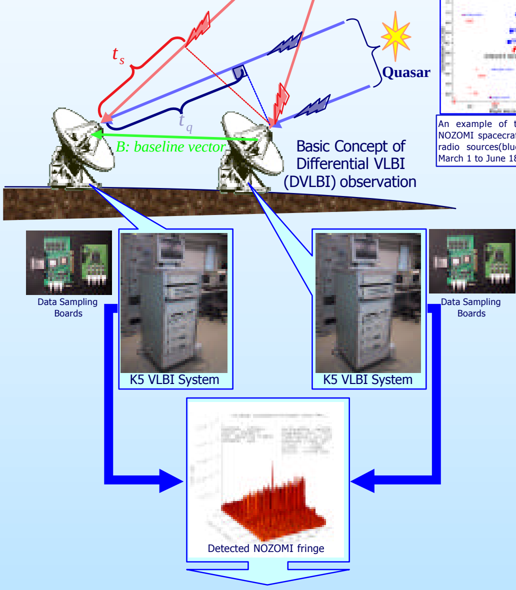
VLBI stations participating to DVLBI experiments







An example of trajectory of the NOZOMI spacecraft(red circles) and radio sources(blue squares) from March 1 to June 18, 2003.



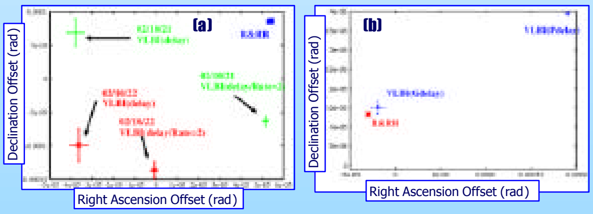
Basic Concept of Differential VLBI (DVLBI) observation

Precise spacecraft positions (5-10 nrad) can be obtained with differential spacecraft-quasar VLBI (DVLBI) observations that directly measure the angular position of the spacecraft relative to nearby quasars. We performed more than 30 DVLBI experiments for the NOZOMI spacecraft navigation from September 2002 until June 2003. NOZOMI, which means "Hope" in Japanese, is the Japan's first Mars probe developed and launched by the Institute of Space and Astronautical Science (ISAS). NOZOMI was originally scheduled to reach its destination in October 1998, but an earlier Earth swingby failed to give it sufficient speed, forcing a drastic rescheduling of its flight plan. According to the new trajectory strategy, NOZOMI's arrival at Mars is scheduled early in 2004 through two additional earth swingbys in December 2002 and June 2003.

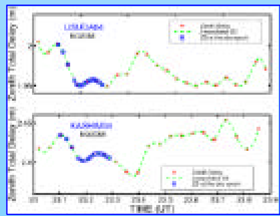
Our main concern was to determine the NOZOMI orbit just before the second earth swingby on June 19, 2003. It was significantly important to get the timing to maneuver the NOZOMI before the swingby. ISAS scientists were afraid that the range and range rate (R&RR) orbit determination might not be available because it was difficult to point the high-gain antenna mounted the spacecraft toward the earth during the period between two swingby events. So we started to support the orbit determination of the NOZOMI using DVLBI technique since September 2002. These DVLBI experiments are also aimed to establish the positioning technology for the interplanetary spacecrafts in realtime.

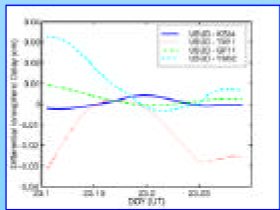
We use nine VLBI antennas in Japan to carry out the DVLBI experiments at X-band. Algonquin 46-m of the Space Geodynamics Laboratory (SGL) of CRESTech also participated in the several experiments. We equipped the state of the art "K5 VLBI system" to these stations. The K5 system is the multiple PC-based VLBI system equipped with a PCI-bus Versatile Scientific Sampling Processor (VSSP) board on the FreeBSD and Linux operating system. The K5 system includes the original software packages which are data sampling and acquisition, real-time IP data transmission, and correlation analysis. For the purpose of analyzing the DVLBI observables we are developing the specific VLBI delay model for finite distance radio source. The model is already implemented in the DVLBI software package. The package will include the DVLBI observation scheduling to take account of the passage of the spacecraft near the quasar line of sight and the propagation delay estimating for the ionosphere and the neutral atmosphere.

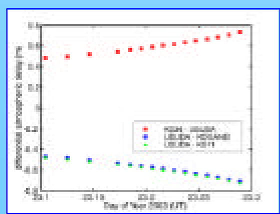
We can successfully detect fringes of NOZOMI range signal for several baselines using software correlation in spite of weak and narrow-bandwidth signal. We provided 15 DVLBI group delay data sets to ISAS to support the orbit determination at the end of May 2003. On the other hand, ISAS scientists have fortunately succeeded to determine the NOZOMI orbit using R&RR observables at the end of May 2003. Preliminary results demonstrate that the DVLBI delay residuals are consistent with R&RR observables. However, the rms scatter between them are relatively large up to several tens nanoseconds. We are now evaluating our DVLBI data sets by comparing with the R&RR results.



Comparison of Estimated NOZOMI position
(a): October 21 and 22, 2002
(b): January 10, 2003







Propagation Delay Correction for DVLBI experiments

Upper Left: Atmospheric zenith delays estimated from GPS data sets. GPS station is located nearby each VLBI station.
Lower left: Differential atmospheric delays estimated from GPS data sets for three baselines.
Upper right: Differential ionospheric delays estimated from CODE global ionosphere data sets provided by University of Bern.

According to the ISAS announcement the NOZOMI has completed its final Earth swingby operation on June 19, and is on its way to Mars. NOZOMI passed within 11,000 km of the Earth in a manuever.