VSOP-2 MISSION OUTLINE AND SATELLITE DESIGN

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ABSTRACT

Following the successes of the VLBI Space Observatory Programme (VSOP), a next generation space VLBI mission, VSOP-2, is being planned in Japan in collaboration with international partners. The VSOP-2 spacecraft will employ a 9-m off-axis paraboloid antenna with dual-polarization observing bands at 8, 22, and 43 GHz, and a downlink data rate of 1 Gbps. With an apogee height of 25,000-km, an angular resolution of about 40 micro-arcseconds will be achievable. A phase-referencing capability is being considered. The scientific objectives include imaging water masers, the innermost regions active galactic nuclei, and the coronae of young stellar objects.

INTRODUCTION

The technique of Very Long Baseline Interferometry (VLBI) has enabled the longest astronomical wavelengths to be used to produce the highest angular resolution images. The VLBI Space Observatory Programme (VSOP), which was realised with the launch of the HALCA satellite in 1997, extended these baselines into space, enabling celestial radio sources to be observed at 1.6 and 5 GHz at resolutions $\sim$3 times greater than with ground-based observations [1,2]. The HALCA satellite was supported by a network of 5 dedicated tracking stations, and VSOP observations were made with arrays of ground radio telescopes from around the world. Following the successes of the VSOP mission, the VSOP-2 project is is being planned in Japan in collaboration with international partners for a launch as early as 2011 [3,4].

THE VSOP-2 SATELLITE

It is assumed the VSOP-2 satellite will be launched on a M-V rocket, and the dimensions of the nose fairing place strong constraints on the size of the deployable antenna. The VSOP-2 spacecraft will employ a 9 m off-axis paraboloid antenna, which is described in more detail elsewhere in these proceedings [5]. The observing bands will be 8, 22, and 43 GHz and the receivers for the 22 and 43 GHz bands will be cryogenically cooled to 30 K [6]. With a planned apogee height of 25,000 km above the Earth's surface, an angular resolution of about 40 micro-arcseconds will be achievable in the 43 GHz band. Details of the orbit and observing system are given in Table 1.

The satellite will be able to receive both left- and right- circular polarizations simultaneously. Observing requires a two-way link between the satellite and a tracking station for the wideband VLBI data downlink at 1 Gbps, and the uplink of a reference signal. The frequency band for the 1 Gbps VLBI data down-link is 37–38 GHz, and for the up-link reference frequency is 40 GHz.

Engineering design and testing is underway for the deployable antenna, antenna pointing, high data rate transmission, cryogenic receivers, and accurate orbit determination required to realize this mission. The on-board radio astronomy antenna, illustrated in Figure 1, is one of the most critical parts of the spacecraft. The development of an off-axis mesh antenna with a segmented (modular) radial rib design has been in progress over the last five years at ISAS. To achieve a surface accuracy as high as 0.4 mm rms, radial ribs will help shape the surface without too much cable structure [5].

A phase-referencing capability, to remove atmospheric phase fluctuations, increase the coherence time and hence the sensitivity, is being considered. (It is, naturally, only the ground-telescopes which are affected by atmospheric turbulence, however the satellite must also observe the calibrator in order to maintain the phase connection to the ground array.) Nodding of the whole spacecraft quickly between the calibrator and target sources may be possible with the addition of 2 Control Moment Gyroscopes to the 4 momentum reaction wheels. For such phase-referencing observations, an orbit determination accuracy of a few centimeters is required, and preliminary studies indicate that this could be achieved by adding GPS receivers with a high precision 3-dimensional accelerometer, or by using signals from both GPS and Galileo (which is scheduled to reach full operational capability in 2008) navigation systems.

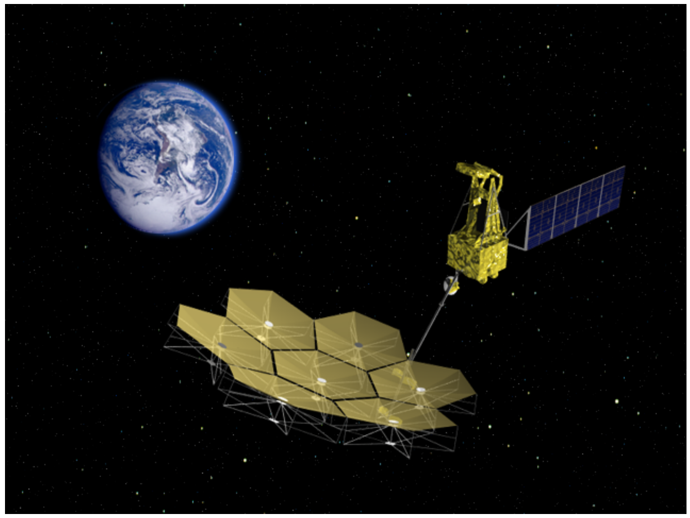

Figure 1: Artist's impression of the VSOP-2 satellite in orbit, showing the 9 m diameter, off-axis Cassegrain design.

The main improvements over the VSOP mission will be: an order of magnitude increase in the maximum observing frequency, from 5 GHz to 43 GHz; an order of magnitude increase of maximum angular resolution; and an order of magnitude increase in interferometer sensitivity for continuum observations.

A satellite mass of about 910 kg is planned — anything greater will require a trade-off in the apogee height. Of this, $\sim$65 kg will be propellant for perigee-raising maneuvers in the first weeks after launch, and for safe-hold events. A power budget of 1.8 kW, generated by the satellite's solar paddle, is assumed.

MISSION OUTLINE

Figure 2 shows the operations flow-chart for VSOP-2 observations. The method is very similar to that successfully used for VSOP observations. The VSOP-2 satellite operates according to the commands sent from the commanding station at Uchinoura, Japan. The satellite receives a reference tone from a link station which is used as the frequency standard for on-board signal processing. The data is acquired, processed, and transmitted to the link station, where it is recorded.

The VSOP-2 satellite, the command station, and the link station operate together as a radio-telescope. The ground radio telescopes and the satellite are operated according to the entire VLBI observation schedule. VSOP-2 observations will have a factor of ten improvement in sensitivity over VSOP observations, due largely to the factor of 8 increase in data rate with VSOP-2. The VSOP-2 data rate of 1 Gbps results in the generation of close to 100 Terabits over the course of an observation. Storing this data on-board for later transmission to the ground is impractical, and a network of tracking stations for real-time data downlink is required, as was the case for VSOP. The data transmitted from the satellite is recorded at the tracking station. For VSOP observations, the recording medium was magnetic tape, however for VSOP-2 it is likely to be exclusively computer disk. The disks recorded at the tracking stations, and at the participating radio telescopes, will be sent to the correlator, or, if sufficiently wide-band networks have become available, the data will be transferred via the internet. The correlator will store the data on disk until correlation is able to proceed. The image of the radio source is obtained by processing the correlator output data.

VSOP observations at 5 GHz, e.g., [7], and ground-based VLBI observations at 22 and 43 GHz, have indicated that many sources still contain compact features. Observations of intra-day variability also indicate the presence of extremely compact components in a signficant fraction of AGN, making these good targets for VSOP-2 observations. The scientific objectives of the VSOP-2 mission also include high angular resolution imaging of the cores, jets, and accretion disks of active galactic nuclei (AGN); galactic and extragalactic water vapor maser sources; and the magnetospheres of proto-stars and young stellar objects. These are considered in more detail in a separate paper in these proceedings [8].

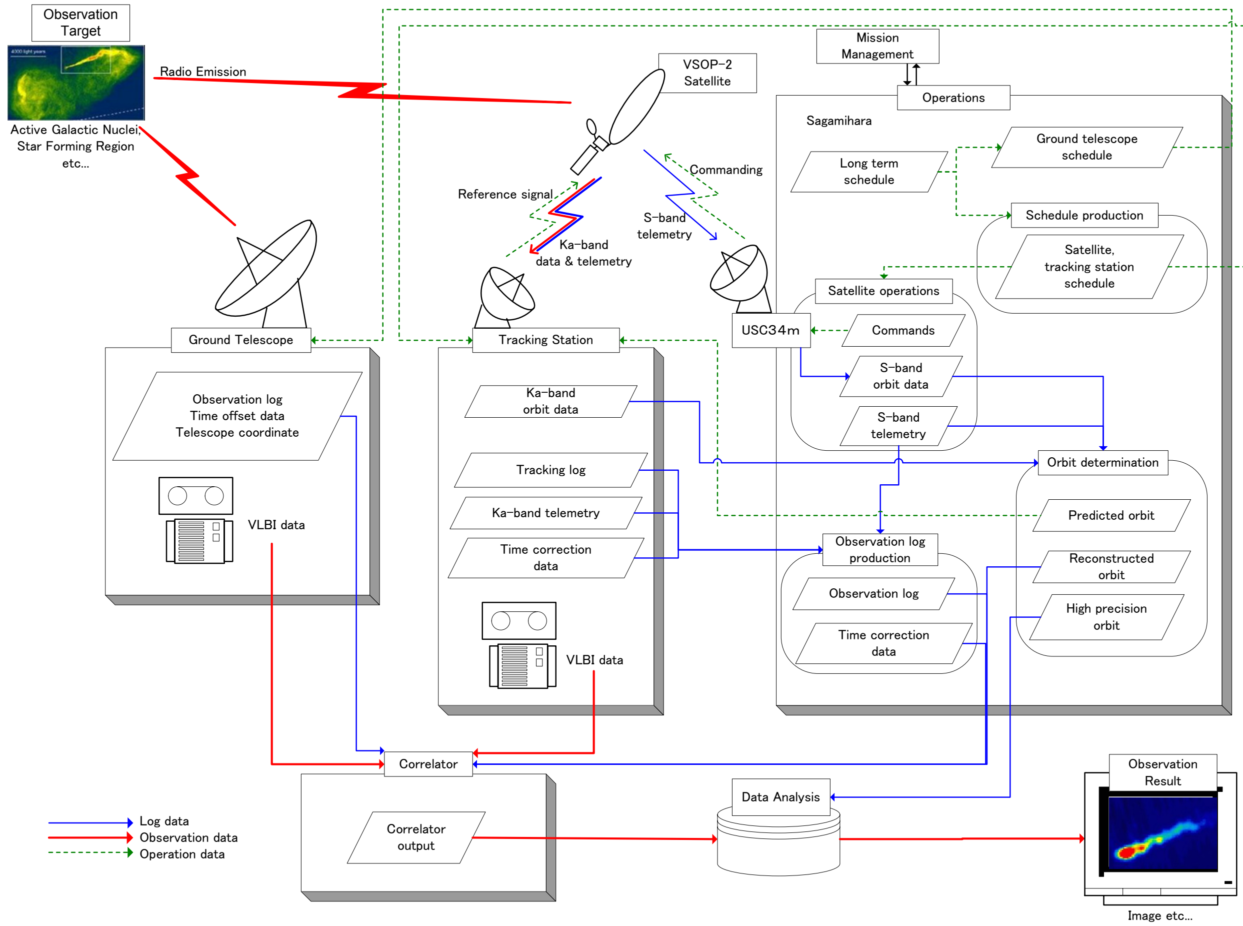

Figure 2: Schematic diagram of VSOP-2 operations flow

INTERNATIONAL COLLABORATION

The VSOP mission was realized through a large international collaboration in terms of ground telescope arrays, correlators, and tracking stations, and orbit determination teams, and a similar degree of collaboration will be essential for the success of VSOP-2.

Within Japan, several new radio telescopes will be available for co-observing. The VERA array of the National Astronomical Observatory is likely to be and important contributor to VSOP-2 as it is able to observe in all three of the VSOP-2 observing bands and its dual-beam design enables routine phase-referencing observing. In addition, the three-station Korean VLBI Network (KVN) is scheduled for completion in 2007, and several new telescopes in China are also planned to become operational before the launch of the VSOP-2 satellite. New telescopes, and upgraded capabilities for existing telescopes, in other parts of the world will enable further improvements in baseline sensitivity for VSOP-2 observations.

International partners contributed 4 of the 5 dedicated tracking stations to the VSOP mission. As a result of the higher apogee height of the VSOP-2 satellite, a smaller number of tracking stations could be used for the VSOP-2 mission, if their geographical locations are optimized. Once again, international collaboration will be important for the success of this aspect of the mission.

Table 1: VSOP-2 satellite overview

Nominal Orbit			
Apogee height	25,000 km		
Perigee height	1,000 km		
Orbital period	7.5 hours		
Orbital inclination	31°		
Precession of AOP ($\dot{\omega}$)	+258 $^\circ$ yr^{-1}		
Precession of LAN ($\dot{\Omega}$)	-167 $^\circ$ yr^{-1}		
Observing System			
Polarization	LCP and RCP		
Bandwidth per channel	128 MHz		
Observing band	8 GHz	22 GHz	43 GHz
Angular resolution[1]	205 μas	75 μas	38 μas
SEFD	4080 Jy	2200 Jy	3170 Jy
7-σ detection sensitivity[2]	23 mJy	50 mJy	107 mJy
. . . to a large telescope[3]	5 mJy	12 mJy	22 mJy
Phase referencing sensitivity[4]	6 mJy	8 mJy	11 mJy
Image noise level[5]	0.24 mJy/beam	0.45 mJy/beam	0.71 mJy/beam

1. The angular resolution given here is the beam FWHM for a source at the orbit normal direction.
2. To a single VLBA (25 m) antenna, assuming a coherence time of 6, 2, and 1 minutes at 8, 22 and 43 GHz.
3. To the phased-VLA (27 $\times$ 25 m)
4. For a 90 minute integration, to a single VLBA antenna.
5. For an observation lasting one orbit (7.5 hr) with the full VLBA.

TIMELINE

The timeline for the VSOP-2 mission, assuming it is selected from the current call for proposals, and that there are no delays in the funding of the mission, is as follows: Proposal submission in September 2005, mission selection in 2006, followed by a formal budget request to the government. Funding would start in the 2007 fiscal year, with two years for Prototype Model development and three years for Flight Model development, and launch on an M-V rocket in the 2011 fiscal year (i.e. April 2011 to March 2012). A mission lifetime of at least five years is planned. For more details about the mission, see the VSOP-2 website, http://www.vsop.isas.jaxa.jp/vsop2 .

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