

Minutes of VSOP-2 Tracking Station Meeting, 10/31-11/01/06

Prepared by Jim Ulvestad, 17 November 2006

Attendees:

ISAS: Murata, Hirabayashi

NAOJ: Inoue, Kobayashi, Kono

JPL: Preston, Jones, Smith, Murphy, Meier, D'Addario, Miller

JIVE: Gurvits

NRAO: Ulvestad, Langston

OAN: Bachiller, Lopez Fernandez

TUESDAY, OCTOBER 31, 2006

VSOP-2 mission update - Hirabayashi

VSOP-2 is now selected. Summary of VSOP mission. Summary of tracking station network. Summary slide of scientific results from HALCA. HALCA last command November 30, 2005, and VSOP project terminated March 2006, at the end of the fiscal year. VSOP was a 17-yr project after real budget was obtained.

Summary of VSOP-2 mission. Key science summary. Goals of 10 times sensitivity, highest frequency, and resolution compared to VSOP. 9m radio astronomy antenna, 1 Gbps downlink, dual polarization. 8, 22, 43, GHz, possible phase referencing. Apogee height 25,000 km, perigee height 1,000 km. Inclination 31 deg. Scientific mission presently known as Astro-G. Discussion of phase referencing, downlink data, 2-way Doppler. Note possible importance of Yebes, South Africa.

VSOP-2 proposal status. Development funds (pre-phase A, 2000-2005), about \$2M. VSOP-2 proposal submitted September 2005, proposed for M-V. Selected over NeXT, Solar-Sail. Space Development Committee, pre-start evaluation, and formal approval. Budget to be announced in December, start in next FY, April 2007. Now in FY06 Phase A. Astro-EII launched in 2005; Astro-F, Akari, IR, in 2006; Hinode (solar), launch 9/06. Gap from 2007 to 2012 for astrophysics missions, with only non-astrophysics missions in this time period. E.g., Venus mission in 2009.

In-orbit configuration of spacecraft shown. Offset Cassegrain, 80 cm link antenna, 20 Watt transmitter. Seven segments to primary antenna, with four different shapes. 3-d sub-reflector mechanism, 2-d adjustment of main reflector. Center of mass just outside main spacecraft body. Spacecraft system block diagram. Solar paddle is rotatable by 260 degrees. 1.8 kWatt

total power at beginning of mission. Parabolic structure by radial ribs and cables. (hoop-rib structure). 48 segments of radial ribs per module. Design goal rms 0.4 mm. 2-stage Stirling cooler, to 30 K, 22 GHz and 43 GHz. Horns are in dewar. 8 GHz not cryogenic. Stirling cooler available inside Japan. On-board receiving system, Q 41-45 GHz, K 21.5-23.5 GHz, X 8.0-8.8 GHz. Japan broadcasting satellite just below 21.5 GHz.

Antenna based on ETS-VIII structure, due for launch in December 2006, with 12 segments. Deployment test of 7 modules shown, 1/2 scale. ETS-VIII modules are about the same size as the VSOP-2 segments, with total area the same as a tennis court. Largest scale is 19 meters. Two antennas, one for transmit, one for receive. No sub reflector, prime focus. Two mechanical actuators for push/pull. Only one set of actuators for entire antenna, not one set per module.

VSOP-2 uplink at 40 GHz, no modulation, 10W transmitter; downlink 37-38 GHz, 20 W from 80 cm antenna, with 48 dBI gain. Data storage 4 TB/8 hours. S-band commanding from Kagoshima. Honeywell CMG with 4 reaction wheels. Orbit determination < 5 cm, with GPS+3-d accelerometers. Phase referencing requirement of 3-degree separation in 1 minute cycle. Maybe 1 or 2 larger missions have used CMGs. Honeywell CMGs are very expensive.

First selected science mission after JAXA merger. Spacecraft and ground segments, not including launch cost, limited to 12 billion yen. Cost estimate for s/c system has gone up by 20%. May need to down scope science payload. NEC bus, with good ISAS experience, knowledge. Science operations and instrumental support are very important. Last M-V launch will be for Hinode solar mission. Will not have M-V any more. Lower-cost M-V may be developed, but cannot rely on this for 2012. Instead, must use H-IIA shared launch or another launcher. Venus mission in 2009 will have to rely on H-IIA, though it was sold with M-V. Uncertainty about VSOP-2 orbit in case of shared launch.

European participation - Gurvits

Three possible funding sources: ESA, EC FP7, National Funding Agencies.

ESA - Recall ESA flexi-mission proposal submitted in 2000. "Warmly received", but no funding with no mission in process. ESA Cosmic Vision adopted as roadmap 2015-2025. Specifies themes, not missions. First call for Cosmic Vision mission expected in January 2007, with deadline 3 months later. Delayed to figure out how to fit in current mission development within funding profile. Expect strong planetary science proposals, unlikely that VSOP-2 fits in. (Launch date is too soon, among other things.) Amount of call is roughly half billion Euros.

FP7 - EVN and Radionet history. Broad involvement of EVN observatories, VSOP users.

High degree of synergy with major developments in radio astronomy. Relevant call for proposals in late 2007, early 2008. Proposal preparation in Radionet has begun. Expect robust internal peer review. If approved, funding for 2008-2012. Joint Research Activity (JRA) on SVLBI is most likely. Networking Activity also in preparation (Lobanov)--means meetings, collaborations, not computing networking. JRA cannot fund bricks, what can it fund?

ESA via National Agencies route - unsolicited proposals favored by ESA, funding at 20 M Euro scale. Coherent support by key national delegations is crucial; national delegation goes to ESA and asks for money. Lobbying of national delegations must start immediately. ESA disperses money in rough proportion to money contributed by national delegations. Updated science case is crucial, and needed by December this year. Hagiwara is working on it. Within 20M Euro, can do what we want to do. (tracking station, etc.)

EVN CBD keeps VSOP-2 on agenda. EVN VSOP-2 contact group formed in 1999. Participation in development of science payload components is possible. Tracking support from Yebes 14-m. ESA kept informed on scientific community interest in VSOP-2. Crystal oscillator, 10^{-13} over 30 sec. 3D linear accelerometer, better than 0.5 nm/s^2 on time scale of minutes. Receiver components, Planck-based. Galileo Rx, European constellation of navigation satellites.

Open issues for discussion. What is needed from Europe? Will ESA allow Astro-G into Cosmic Vision (2015 +). Exploit benefits of synergy with EVN-2010 (correlator), EXPRs, SKADS, SKA. VSOP-2 in FP7. National funding sources. Science case sharpening needed. Phase-referencing emphasized. Higher data rate possibility? Implications of new launcher. Exploiting synergy with SKA. Resolution matching with mm VLBI.

U.S. VSOP-2 support plans -- Murphy

NASA funding emphasizes shuttle replacement. Need to find a suitable competition and win selection. Currently, only game is Mid-Ex Mission of Opportunity, \$35M for portion of mission. Good card, VSOP-2 already approved in Japan, ARISE decadal report legacy. Bad card, small USVLBI community, little support available for proposal.

Time scale for NASA/JPL summarized:

Sept 06, VSOP-2 presentation at JPL.

Nov 06, JPL decides on concept studies to support

Nov 06 - March 07. Undertake concept study

Mar 07 - JPL concept study review

Mar 07 - Draft MidEx AO released

Apr 07-Jan08 Prepare VSOP-2 Midex MoO

Jan 08 Submit VSOP-2 Midex MoO

Jan 08+ MidEx selection, 3-6 months

Possible uses of \$35M from MoO proposal include the following: VLBA, VLBA correlator, GB tracking station, JPL tracking stations, on-board GPS receiver, U.S. science support, JPL project office, other.

Concept study. Determine use of MoO resources, distribution of responsibilities. Top 3 technical issues: tracking stations, GPS/phase-referencing study, correlator and VLBA upgrades required. Top 3 programmatic issues: sharing of mission responsibilities, ITAR/TAA/MOU (Technical Assistance Agreement) issues, formation and operation of US MoO team. Support from outside JPL: NRAO+university support.

ASTRO-G Ground Tracking Station Plan - Murata/Kono

Start from HALCA. Functions: uplink reference, data demodulation, data recording, telemetry data extraction, Doppler measurement. Difference from Halca: Uplink 40 GHz, downlink 37-38 GHz. Data demodulation 1 Gbps QPSK. Data recording, VSI (VERA, Mark 5, K5). Telemetry data extraction. Doppler measurements. No phase-cal pulse. Question--why use 38 GHz rather than 26 GHz? Lower frequency is easier, there is 1.5 GHz allocation at 26 GHz. Can use very narrow-band uplink, maybe at 15.3 GHz as for VSOP.

Downlink of 20 W, 37-38 GHz, 1 Gbps, QPSK. NASA is aiming to use a 22-24 GHz uplink for support of JWST. No downlink carrier. Data transmission, current design, reference phase transfer. 6 LNAs, 1 per polarization per frequency. IF 6.6-8.8, base band 1.3 GHz. Q band LOs fixed, at 34 and 36 GHz. Suggest doing 1 bit on spacecraft, 2 bit, 2 Gbps on ground telescopes, to get more sensitivity. This helps in continuum, but not in line. 2-2 bit is 0.88 sensitivity, 1-1 bit is 0.90 sensitivity, 1-2 bit is 1.06. But, for lines, you lose, and want 2 bits in both places. Thus two modes, 2-bit or 1-bit on spacecraft. Some discussion of telemetry block insertion in downlink data. Easy to get telemetry data out at tracking station. New TWTA for VSOP-2 based on 42-44 GHz 30 Watt device from NT-space. Possible in-band interference to nearby radio telescope observing at Q band? 38 GHz downlink may be in band of radio telescope receiver.

Link budget. Some questions about 26 vs. 37 GHz. Impact of rain at the different frequencies. Chart of days per month where maximum rainfall is 2 mm/hr or 5 mm/hr at Usuda. Phase reference link has 26 dB margin, even with pessimistic assumptions. Thinking of not doing Doppler compensation, but group believed it was necessary. Summary of ground telescope frequency coverage.

Number of tracking stations -- Murata

Plot of tracking time vs. no. of tracking stations, as function of argument of perigee (small omega). Shows VSOP-2 modification to FAKESAT. Requirements--need 3-4 tracking stations. Uniform longitude coverage. Low latitude is better (i.e., low absolute value of latitude). Discussion of second ISAS/JAXA tracking station in South America. But there is no specific mission funding for this.

Much discussion about how to come up with the best combination of tracking stations. Pick combinations of 3 or 4 that give the amount of tracking (on average) above some minimum value, then see which is best politically? Note that weather matters at 40 GHz downlink. Think about possibly adding a station in India, well separated from other candidates in longitude.

Usuda station -- Kono

Usuda station 10m, same type of antenna as NAOJ antenna at Misuzawa, which operates at Q band. Guess at 44% aperture efficiency, but needs confirmation. Will check the Misuzawa value. Ka band, expect $T_{rx} < 50$ K with cooled LNA, T_{sys} 140K in fine condition. Block diagram. Prospective block diagram Without doppler compensation was shown, but is missing the blocks needed to measure frequency error. Possibility of doing Doppler compensation on board was raised, and thought to be undesirable. Conclusion -- should use Doppler compensation on link. Minor discussion of clock "fluctuation" due to Doppler on downlink.

KJJVC, Korea-Japan Joint VLBI Correlator. 16-station correlator in Seoul, data rate up to 8 Gbps/station. Inputs from Mark 5B, DIR-2000(VERA), K-5, Optical fiber.

Yebes tracking station -- Lopez Fernandez

14m could be used full time, no longer being used. Need to do some work to repair antenna. Observatory started in 1973 with optical telescope. 14m radio telescope inside radome, installed 1976. First light for 40m expected in 2007. Developed HEMT LNAs. About 70 km east of Madrid. Average precipitable water vapor is 7 mm, with rain 20-30 days/year. Plot of water vapor vs. time of year shows typical 5mm water vapor in winter, 15 mm in summer. Not very windy, day/night temp. difference of 14-20C, snow only 5-10 days/yr. Used S/X/Q bands. Quit observing in 2004, since failure of HP1000 control computer. Also, need servo replacement. Has two sub reflectors, original for 7mm, later added S/X sub reflector. ESSCO system.

Original lifetime 15 years, greatly exceeded. Twin of FCRAO, Metsahovi, GB tracking station. Surface accuracy of reflector was 0.2mm, is now 0.5mm, could get back to 0.2 mm by realigning with holography. Pointing accuracy 0.2 mdeg, tracking 0.1 mdeg, maximum speed 1 deg/sec, 48 panels. Radome repair advisable. Needs sealing, replacement of 10%

panels (total no. of panels is 350), and painting. 1 dB attenuation at 38 GHz. Noise temp contribution < 100 K at 10 deg. elevation. Surface alignment is advisable. mm sub reflector is 1.08 m, S/X is 2.2 m. Measured surface 10 years ago, then added sheets to mm sub reflector to improve efficiency. Angular acceleration 1 deg/s². Improving servo system, thinking of changing motors and encoders. Would like to reproduce systems for 40m antenna to save maintenance costs. Needs azimuth bearing replacement. Unfully compensated backlash did have 20 arcsec error, now increased to 30 arcsec due to wear on bearing. Servo system needs upgrade. Antenna has 30% efficiency at Q band, could be better. Was 60% when surface was 200 microns. Madrid altitude is 1000 m. Maser is at 40m telescope, 200m away. No manpower, would need to hire operators and technicians.

Summary of mandatory changes, and advisable changes. Budget to 2012 looks like 2 M Euro, but VLBI up/down link appears to be under costed. 6 FTE/yr starting 2011. Need to develop common design.

Langston - GB tracking station

Discussion of 140-ft (43m) antenna project with Air Force, 20m Navy antenna. Surface rms 0.8mm. Prime focus optics. 2 deg/sec. 10%-15% efficiency possible at 38 GHz. Beam is 1.2 arcmin, needs to have good enough pointing.

Antenna costs a lot. Design engineer and software cost a fair amount. Individual modules cost less, but add up. Getting a free antenna helps. Need to share in the design engineer and software area. Better from GB point of view to be at 26 GHz, due to weather and antenna capability. List of different subsystems given, with hypotheses about who might design or build them, and how one might divide up the work. Discussion of need to flow down from a block diagram and overall system design, not start from subsystems going up. How we arrive at the common system design still remains to be discussed. Some discussion of doing autocorrelation and using the VSOP-2 antenna as a single-dish transient detector. Link margin is pretty good. GB may prefer to use the 43m antenna, already resurrected, though its slew rate is only 25 deg/minute.

JPL tracking station - Jones, Murphy

Prototypes of low-cost antennas working up to 40 GHz. 6m hydro formed antennas. 12m paneled Patriot antenna, Cassegrain. Simultaneously cover 8-9 GHz, 30-40 GHz. 45 K Tsys measured at 30-40 GHz. Slew fast enough for LEOs, altazimuth. 12m is 40% at Ka band, degrades during daytime due to thermal effects, probably fixable. 6m above 50% at Ka band, both day and night. 6m cost about \$300K for mechanical bits, another \$100K for receiver, with mount built at JPL. 12m cost about \$400K except for electronics. Pointing is better than 0.1 HPBW for 6m, occasionally worse for 12m. Might even take the two 6m antennas and the 12m antenna away from JPL, since DSN will be done with them in a couple years.

Patriot assembled in 2 weeks by 2 people at JPL--bolted and not welded. Will it last forever without welding?

WEDNESDAY, NOVEMBER 1, 2006

Tracking station lessons learned - Ulvestad, D'Addario, Hirabayashi, Langston, Murata

Coherence losses at correlator probably due to unmodeled accelerations. No closed loop tracking. Predicted orbits were pretty good, so time correction files were smooth. Need to calibrate tracking station zero-offsets and biases very well.

Global schedule file was important. All files should be available to all mission elements. Pre-launch testing using satellite simulator was good. Important for knowing station could decode the frames, knowing satellite could lock to uplink carrier, etc. Tracking stations also need a local satellite simulator for station verification. Each mission element should have fault detection built in. Time Correction File worked well. No need for space H maser. Very desirable to have one design. Could have subcomponents made by different groups, but then interface control and management becomes a problem. One kind of recording system. Would be nice to have only one correlator. But not practical given the available funding. Discussion of tracking station simulator, etc.

VSOP-2 timeline shown, with 2 years for engineering model, 3 years for flight model, starting in April 2007. In 2nd year (April 2008 to March 2009), need some ground tracking hardware for testing of the engineering model of the spacecraft; this hardware can later go to a station. Then use it again with flight model 6+ months before launch in February 2012. Ground tracking hardware means demodulator, etc. Earliest possible funding in U.S. is October 2008. Therefore, there's essentially no possibility for U.S. design to be made and adopted elsewhere, Mission team would like 1 Gb/s QPSK demodulator, which has been worked on at JPL.

Telemetry interface (blocks embedded in the science data) is important. Specification was late, as were decisions about delivery. Figure out what to do early.

At Usuda, some instruments didn't work well at first. Demodulator started out not so great, became better. Contract out demodulator. Maybe don't need to change telemetry format from VSOP to VSOP-2, but different format may be needed to get GPS data and accelerometer data down. For recording, use VSI interface. Downlink frequency comparison and 2-way phase residual measurement are redundant with 2-way Doppler, so we can rely on one or the other, and not extract both at station. On-board recorder will be 1 Gbyte, whereas VSOP was about the capacity of a floppy disk. So the GPS/accelerometer data might come down by S-band link. No need to change file formats for VSOP-2. E.g., global schedule file for SRT, orbit prediction file (NAIF format). NAIF format now can be generated in Japan.

Do we need to send Doppler data at all? We generally think so. Backup to GPS, also for orbit prediction. May need to update Doppler data format. Make telemetry data available on ftp site every 10-15 minutes? How do we report momentum dumping?

Correlator lessons learned - Ulvestad

Most lessons were similar to those presented in tracking station presentations. Summarized requirements for timeliness of data, needing disks within a week and reconstructed orbit within a week. Need for identical interface to all tracking stations, strong desire for identical internal tracking station designs. In the end, DSN and Green Bank stations worked equally well. Usuda station was less reliable because the bias in the time offset was not constant, but changed by some small number of microseconds.

Discussion of tracking stations - All

How do we progress, next year? Because of time and funding, only viable option is Japanese-led design. Need rough block diagram and cost estimate for partners to come up with proposals to funding agencies. Need goal for clear deliverable before next meeting. Must embed station in the environment where it will be operated.

Discussion about frequency allocations. JPL planning to use 25.5-27 GHz for lunar missions. Ionosphere error on 2-way link shown as function of uplink and downlink frequencies. Conclusion is that uplink and downlink should be near each other in frequency for the phase link, so that ionosphere effect on uplink and downlink are similar in size. Could put them both near 15 GHz, with data downlink at 38 GHz, but this means 2 transmitters, etc. ITU tables may show 26 GHz band uplink to satellite? 25.5-27 GHz. Should decide about modulation, whether it is 1 Gbps QPSK or higher order. Higher order modulation takes more power, but may mean that an entire 1 GHz band doesn't need to be used. Need to convert theoretical frequency allocation into actual assignments for VSOP-2 mission. Note that 25.5-27 permits standard frequency and time transmission from Earth to space, so perhaps the phase link could fit in this allocation.

Next meeting - All

Another tracking meeting in February 2007, after rough block diagram is available. Discussion about Yebes and Green Bank, but Yebes is better in February--possible transportation problems to GB due to weather. Lessons Learned from VSOP meeting may be held April 2 or 9 in Hakone, possibly overlapping a tracking meeting. Additional tracking meeting in Green Bank in summer?

Action items, with assignments and due dates

- (1) Assess frequency coverage at 22GHz vs. science goals, and decide whether lower frequency boundary should be changed to be lower than 21.5 GHz (water at $z=0.03$). Murata, 1 December 2006.
- (2) Make informal mission request to Europe about the contributions desired from Europe. Hirabayashi/Gurvits, 11 December 2006.
- (3) Form team for MoO proposal to NASA. Murphy, 1 December 2006.
- (4) Generate letters to NASA and ESA requesting mission support, from JAXA/ISAS. Hirabayashi/Preston/Gurvits, 31 January 2007.
- (5) Assess possibility of using 26 GHz downlink, plus timing uplink near 26 GHz. Murata/Kono, plus D'Addario to contact JPL frequency coordinator (Ted Peng). 15 December 2006.
- (6) Compute tracking time availability for combinations of 3 or 4 stations, determine which ones have 75-80% coverage, and decide which combinations are politically feasible. Murphy/Murata, 1 December 2006.
- (7) Generate agreed-on link budgets with common assumptions, for different tracking stations and antennas. Kono/Langston/Lopez Fernandez, 15 December 2006.

-- To be followed by decision on 1 Gbps QPSK vs. higher modulation
to use only part of 1 GHz allocation
- (8) Estimate performance of Usuda 10m antenna at 26 GHz and 38 GHz. Kono, 22 November 2006.
- (9) Check on availability of 1 Gbps QPSK demodulator at JPL. Murphy, 1 December 2006.
- (10) Propose method to pass on data from GPS, accelerometer, and momentum dumps. Murata, 30 April 2007.
- (11) Assess possibility for VLBA correlator to take on Space VLBI processing at 1 Gbps, assuming that WIDAR correlator takes over all normal VLBA processing. Ulvestad/Romney, 15 December 2006.

- (12) Draft common tracking station/link design and specification. Murata/Kono, 31 December 2006.
- (13) Provide updated science case. Hagiwara, 30 November 2006. Makes use of ARISE Executive Summary, to be provided by Ulvestad.
- (14) Next meeting, Yebes. Bachiller/Hirabayashi, February 2007.