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Permanent Link to Innovation: Where Is GIOVE-A Exactly?
2021/06/09
Using Microwaves and Laser Ranging for Precise Orbit Determination By Erik Schönemann, Tim A. Springer, Michiel Otten, and Matthias Becker Though Galileo's GIOVE-A is a test satellite not necessarily ready for scientific use, orbit analyses with a reduced accuracy can help to identify weaknesses and suggest improvements. This month, the authors share work being carried out to precisely determine the orbit of GIOVE-A using SLR and microwave observations. This preliminary investigation will benefit the procedures to be implemented for the future Galileo constellation. INNOVATION INSIGHTS by Richard Langley WE USE THEM FOR LISTENING TO MUSIC, for routine surgeries, for making a point in a presentation, and even for hanging pictures straight. Of course, I'm talking about lasers. Invented in 1960, the laser (an acronym for light amplification by the stimulated emission of radiation) has become ubiquitous in modern society. Every CD and DVD player has one. Many printers use them. But lasers are also used in a wide range of industrial and scientific applications including determining the orbits of satellites through satellite laser ranging (SLR). In the SLR technique, pulses of laser light from a ground reference station are directed at satellites equipped with an array of corner-cube retroreflectors, which direct the pulses back towards a collocated receiving telescope. By accurately measuring the two-way travel times of the pulses and knowing the location of the station and other operating parameters, the positions of the satellites can be determined. A network of SLR reference stations around the globe is used to monitor the orbits of satellites over time and their variations have been used by scientists to improve our knowledge of the Earth's gravity field; to study the long term dynamics of the solid Earth, oceans, and atmosphere; and even to verify predictions of the General Theory of Relativity. The first SLR measurements were obtained from the Beacon Explorer-B satellite, which was launched in October 1964. Since then, dozens of satellites equipped with corner-cube retroreflectors have been launched including a number of radio-navigation satellites. Every GLONASS

satellite is equipped with retroreflectors and two GPS satellites have been equipped—SVN35/PRN05 and SVN36/PRN06. The COMPASS-M1 satellite in medium Earth orbit carries retroreflectors, as do both GIOVE-A and –B, the Galileo test satellites. Precise orbit determination of radio-navigation satellites using SLR has the advantage of being unaffected by any onboard satellite electronics and associated signal biases. Radiometric observations of a satellite's microwave signals, on the other hand, are influenced by the satellite's clock, for example, and its effect must be estimated to obtain precise (and accurate) satellite orbits for navigation and positioning. Therefore, a comparison of SLR- and microwave-derived orbits can be very useful for studying the performance of the data measurement and orbit-determination processes of both techniques. In this month's column, we take a look at some work being carried out to precisely determine the orbit of the GIOVE-A test satellite using SLR and microwave observations. This preliminary investigation will benefit the procedures to be implemented for the future Galileo constellation. "Innovation" is a regular column that features discussions about recent advances in GPS technology and its applications as well as the fundamentals of GPS positioning. The column is coordinated by Richard Langley of the Department of Geodesy and Geomatics Engineering at the University of New Brunswick, who welcomes your comments and topic i deas. To contact him, see the "Contributing Editors" section on page 6. The navigation office of the European Space Operations Centre (ESOC) is engaged in various activities using observations of the Galileo test satellite, GIOVE-A (Galileo In-Orbit Validation Element-A), recorded at the Galileo Experimental Sensor Stations (GESS). The work includes the assessment of the quality and performance of GIOVE satellite observables and the testing and improvement of orbit-determination software. These activities support the long-term goal of advancing the scientific applications of the future Galileo constellation. Since the launch of GIOVE-A on December 28, 2005, various tests have been carried out to analyze the quality of the new code (pseudorange) and carrier-phase observables derived from tracking the satellite's microwave signals. All of these tests demonstrate the advantages of the new signal structure compared to that of legacy GPS signals. In general, the reduction of the noise by factor of 4-5 as well as a reduction of the code multipath by approximately a factor of 1.2 (GPS C1C versus GIOVE-A C1B/C1C) could be seen. As the comparison of observations is done indirectly (GPS and GIOVE-A have different orbits) and the databases used for most analyses published up to now is sparse, a deeper analysis of the signal quality parameters seems appropriate, especially as data quality has a direct impact on the precision of orbit determination. Our analyses, presented in the first half of this article, are based on a broad base of data from most of the stations in the GESS network. Because of the difficulty in accessing the phase multipath directly, we first evaluated the signal strength and the code multipath, which gave the first hint of the multipath behavior. In order to compare GPS and GIOVE-A data directly, only data received from the same elevation angles and azimuths were used. Subsequently, we present an analysis of the phase residuals derived by precise point positioning. The second part of this article focuses on the precise orbit determination or POD of the GIOVE-A spacecraft. The Navigation Package for Earth Observation Satellites (NAPEOS) software used at the ESOC Navigation Support Office allows microwave (radiometric) and satellite laser ranging (SLR) observations to be used either separately or together. The two methods are different due to different tracking networks and the different sensitivity of the observables to atmospheric effects and in their noise levels. We will present the orbit results focusing on internal orbit consistency checks and SLR validation of the microwave-based orbits. Data Analysis We first describe the procedures used for analyzing the microwave data followed by those used for the SLR data. Microwave Analysis. For the GIOVE-A signal analysis and precise orbit determination we used the RINEX data from all of the GESS stations available from the GIOVE archiving facility (see TABLE 1). All stations are equipped with GPS/Galileo antennas, built by Space Engineering S.p.A. and Galileo Experimental Test Receivers (GETRs), built by Septentrio. The data, containing tracking data of all GPS satellites and the GIOVE-A satellite, is given in the RINEX 3.00 data format with a sampling interval of 1 second. To save on storage space for the long-term analyses, such as orbit determination, the RINEX data is decimated to 30-second samples and Hatanaka-compressed, using a test version of the Hatanaka software for the RINEX 3.00 format. The signal analyses shown here were carried out using GNU Octave, an open-source program for performing numerical computations similar to Matlab, and different scripts developed by the Institut für Physikalische Geodäsie at the Technische Universität Darmstadt. These analyses cover a selection of the designated Galileo signals recorded by the GESS within the time span from December 16 to 27, 2006. Within this time period, the current GPS signals, as well as the GIOVE-A signals E1 and E5, shown in TABLE 2, were recorded. The table also shows the signal components as well as the RINEX observation-type identifiers, which we use in this article. The stations used for the analyses show a quite similar level of performance in general. There are stations with different behaviors for single signals, as for example GIEN with a stronger code multipath behavior on C1B and C1A, but no station with a considerably different performance level could be identified. The averaging over the data from all sites reduces the station-dependent effects such as multipath and the atmosphere to a large extent, and gives a good indication of the mean signal performance. The analyzed phase residuals were taken from the processing carried out for the second part of this article. Hence, they include observation data over an extended period of 149 days and were limited to the GIOVE-A C1C/L1C and C7Q/L7Q signals. This extended data period is from December 12, 2006 (day of year 346), until May 26, 2007 (day of year 146). During this interval, there is a period where no GIOVE-A data was available due to maintenance of the spacecraft. This gap occurred from February 12 to 28, 2007. So in total we have analyzed 149 days of microwave data. Because there are some differences between the results before and after this gap in February, many of the statistics are given for the first and second part separately. The first part covers December 12, 2006, until February 11, 2007; the second part covers March 1, 2007, until May 26, 2007. We performed the precise orbit determination using the NAPEOS software, a general-purpose software package for orbit determination, prediction, and control, supporting all phases of an Earth-observation mission in terms of mission preparation and operations. For the GIOVE-A analysis, the three main NAPEOS programs we used are GnssObs, Bahn, and Multiarc. GnssObs reads, cleans, and decimates the RINEX data and converts the data into the NAPEOS internal tracking-data format. The NAPEOS tracking-data format contains the ionosphere-free linear combination, for both code and phase, of the RINEX observations. For GPS, the ionosphere-free linear combination is based on the combination of C1P and C2P code and L1P and L2P phase measurements. GIOVE-A offers several different observables allowing for many different ionosphere-free observations. For most of the work presented in this article, we have used the ionosphere-free linear combination of the C1C and C7Q and L1C and L7Q observations for code and phase respectively. The next module, Bahn, performs the parameter estimation. In this step, we use the ionosphere-free code and phase observations at a sampling interval of 5 minutes, and we have applied an elevation angle cut-off of 5 degrees. The data is processed in batches of 24 hours, thus resulting in 1-day-arc solutions. The estimated parameters in these daily solutions are the GIOVE-A state vector (position and velocity), five dynamical orbit parameters from the extended Center for Orbit Determination in Europe (CODE) orbit model, a GIOVE-A clock offset for each epoch, all receiver clock offsets for each epoch, one GPS-GIOVE-A “intersystem bias” parameter per day for each station except for a selected reference station, and the carrier-phase ambiguities (integers not resolved). The station coordinates are estimated but tightly constrained (1 millimeter) to their a priori value. We obtained the a priori station coordinates by combining the full set of daily solutions. Despite the fact that the 13 GESS stations provide very good global coverage, it is expected that 24-hour solutions will not give the most precise GIOVE-A orbit estimates. To generate longer arc solutions, we have used the Multiarc program. This is a tool that has recently been added to the NAPEOS software package. It allows for a rigorous combination of normal equations, also referred to as normal equation stacking, which are generated by Bahn. During the normal equation combination, the satellite orbit parameters may also be rigorously combined, thus effectively leading to multi-day orbital arcs. For the work presented in this article, we have used Multiarc to generate solutions with arc lengths of 1, 2, 3, 4, and 5 days. We also used Multiarc to compute accurate a priori station coordinates by stacking all available 1-day normal equations. Satellite Laser Ranging Besides the 13 GESS stations, GIOVE-A is also tracked by more than 17 different SLR stations around the world. For most periods of the mission, the tracking has been consistent enough to allow for GIOVE-A POD using only the SLR data. As the SLR data is completely independent of the microwave data, the resulting orbit solutions will be to a large extent independent as well and thus can be used to give an indication of the achieved precision of the different microwave solutions. The orbit determination strategy used for the SLR solutions is very similar to the one used for the microwave orbits with the main difference being the increased arc-length of 7 days. The same satellite parameters are estimated as with the microwave solutions: the GIOVE-A state vector and five dynamical orbit parameters from the extended CODE orbit model. No further parameters need to be estimated and all corrections applied to the SLR data are according to the International Earth Rotation and Reference Systems Service 2003 standards and, for station coordinates, we used those from the rescaled International Terrestrial Reference Frame 2005 solution. As the noise level of the SLR data is very low, the measurements can also be directly used to give an indication of the precision of the radial position components of the different microwave solutions by computing the SLR residuals without using them in the estimation process itself. Combined Microwave and SLR Analysis. In this step, the SLR data was added to the microwave data in the 24-hour solutions. For the data weighting, we used 100 millimeters for SLR and 1000 millimeters and 10 millimeters for GIOVE-A and GPS code and phase observables respectively. The only change in the analysis strategy in this case was that we now processed the SLR data in 24-hour solutions and not in 7-day batches. All the processing options remained as described in the two previous sections. The resulting 1-day solutions, or rather the associated normal equations, were used in Multiarc to generate combined solutions of different arc lengths. Microwave Data Quality We now take a detailed look at the quality of the microwave data in terms of signal-to-noise ratio (SNR), code-tracking noise and multipath, carrier-phase-tracking noise, and carrier-phase residuals. Signal-to-Noise Ratio. The SNR (or equivalently carrier-to-noise-density ratio, C/N0) is strongly dependent on the satellite transmitter, the signal path through the atmosphere, and the receiver configuration (ground station, antenna, receiver, cable, etc.). Hence the SNR cannot be seen as an absolute value. The SNR is specific to the position, the equipment, and the time. Furthermore, the determination of the SNR values depends on the receiver and the firmware used. As a result, SNR values from different receivers cannot be readily compared. Nevertheless, using only one type of receiver, assuming similar effects on all the different signals at the same epoch, and taking averages over a long time span, we expect the relationships among the signals to be constant. Based on this assumption, we can use the SNR values given in the GESS RINEX files without adjustment. To compare the GPS with the GIOVE-A SNR values, we ordered the corresponding SNR values of all stations on all days by satellite position into a grid with widths of 5 degrees in azimuth and 5 degrees in elevation angle. For the evaluation, we took the grid cells occupied by both GPS and GIOVE-A values and computed the median over all the cells of equal elevation angle. The median per elevation-angle bin for each signal is shown in FIGURE 1. FIGURE 1. Signal-to-noise ratio, GPS versus GIOVE-A As can be seen from the figure, the signal strength of the GIOVE-A C8Q observable ranks best, followed by the GPS C1C, GIOVE-A C7Q, C5I/C5Q, C1A, and C1B/C1C. The weakest signal is found for the GPS C1P/C2P observable, with a maximum signal strength of 40 (receiver-dependent unit, approximately dB-Hz) at the zenith. Comparing the GPS open signals versus GIOVE-A, GPS C1C is considerably stronger than the GIOVE C1B/C1C. According to the GPS and Galileo interface control documents, GIOVE-A C1B/C1A should show up with a stronger signal strength than GPS C1C. The power levels guaranteed on the Earth’s surface are -160 dBW for GPS and -158 dBW for the future Galileo satellite signals except for the BOC(10,5) and BOC(n,m) modeled signals, for which a power level of even -155dBW is guaranteed. But looking at the SNR values shown in Figure 1, we see that the GIOVE-A C1B/C1C is worse by approximately 4 dB than the GPS C1C. But keeping in mind that GIOVE-A is an experimental satellite, an increase of the signal power for the future operational Galileo satellites should improve the signal performance above that shown in this article. Code-Tracking Noise. For signals containing data and pilot components, as in the case of those from GIOVE-A, the code-tracking noise can easily be computed as the difference between the data and the pilot signal. The advantage of this computation scheme is that both signals are influenced by identical error sources (atmospheric errors, multipath errors, receiver errors, etc.). Based on the assumption of equal uncertainties in the two components, we divided the resulting noise values by the square root of two to specify the noise level of each part according to the laws of error propagation. TABLE 3 shows the code-tracking noise for the two analyzed GIOVE-A codes sorted by elevation angle.

The median code-tracking noise is 0.62 meters for C1B/C1C and 0.35 meters for C5I/C5Q, for observations below an elevation angle of 5 degrees. For the C1B and C1C code measurements, the noise median stays below 0.2 meters for an elevation angle above 25 degrees, whereas the median for the C5I and C5Q code measurements for elevation angles above 35 degrees even comes down below 0.1 meters. The results discussed above are consistent with the code-tracking noise values published previously. Code Multipath. We computed the relative code multipath effects as code minus phase differences assuming the amplitude of phase multipath to be insignificant compared to the amplitude of the code multipath. Ionospheric effects were taken into account by using the phase measurements on two frequencies in the usual way: In this equation, CMPx is the estimate of the multipath error on the code, Px and Lx are the code and phase measurements of the same frequency, while Ly is the phase measurement used to correct the frequency-dependent ionospheric effect. The constant, , describes the relationship of the ionospheric behavior for the two frequencies. In order to compare the code multipath level of GPS versus GIOVE-A, we sorted the multipath values using a grid covering the sky with widths of 5 degrees for both elevation angle and azimuth as before. FIGURE 2 shows the median standard deviation of the code multipath values, derived in each grid cell per day and station, versus the elevation angle. No significant difference between GPS C1C and GIOVE-A C1B and C1C, the open code signals on G1/E1, could be found. The code multipath behavior of the GPS precise codes are comparable with the GIOVE-A C5I, C5Q, and C7Q, whereas the C8Q shows the least code multipath effects closely followed by the GIOVE-A C1A, the public regulated service signal. FIGURE 2. Code multipath, GPS versus GIOVE-A Carrier-Phase-Tracking Noise Analyses. In the same manner as that carried out with the code, we computed the GIOVE-A carrier-phase-tracking noise as the difference of the two components (pilot minus data). To accommodate the effect of error propagation, the resulting errors were divided by the square root of two. The resulting phase-tracking noise values were sorted by elevation angle and can be found in TABLE 4. In conformity with the theory that the phase-tracking noise is independent of the modulation scheme, both signals (L1B/L1C and L5I/L5Q) show the same results in units of cycles. Looking at the results in units of distance, GIOVE-A L1B/L1C shows up with a mean phase noise of 0.7 millimeters and L5I/L5Q with 0.9 millimeters. These values confirm those of previous studies. Carrier-Phase Residuals. Phase residuals contain the phase tracking noise, multipath, as well as all unmodeled remaining errors such as antenna calibration inaccuracy and tropospheric effects. The magnitude of the residuals can be seen as an indicator for the observation and model accuracy as well as for measurement quality. The following analyses are based on the ionosphere-free linear combination (GPS L1C/L2P, GIOVE-A L1C/L7Q), computed with NAPEOS. The analyses include data of the 13 GESS over a period of 149 days. To compare the GPS and GIOVE-A residuals, we sorted them into a grid with a width of one degree in both satellite azimuth and elevation angle. Only data in overlapping grid locations were compared to make sure the data was affected in a similar way by multipath or other disturbances. To properly interpret the results, we should mention that for GIOVE-A, 0.06 percent of the ambiguities (2501) were not fixed correctly whereas for GPS all ambiguities were fixed correctly. Looking at the GIOVE-A observations that were correctly fixed, we find a significantly larger number of rejected observations. The number of rejected observations is less by one third for GPS (6 percent) as for the GIOVE-A (9 percent) data. Due to the small number of GIOVE-A observations for elevation angles above 86 degrees, the outlier-cleaned mean as well as the standard deviation at this elevation-angle range are not meaningful. For all elevation angles, GIOVE-A residuals show a lower standard deviation than GPS, indicating a superior performance of GIOVE-A signals. Phase and Code Validation in Processing. Looking at the quality of the code and phase measurements on the different signals, it is conspicuous that GIOVE-A C1A/L1A and C8Q/L8Q rank best, whereas for the current processing of GIOVE-A data, usually the C1C and C7Q signals are used. This leads to the question of which is the best signal combination for GIOVE-A. Hence, we processed 10 days of GIOVE-A data, using different signal combinations. Presently the processing of the C8Q/L8Q signals is not yet implemented in NAPEOS. However, we were able to process the GIOVE-A C1A/L1A – C7Q/L7Q combination. The root-mean-square (RMS) of the code results were reduced by a factor of approximately 1.4 using L1A/C1A compared to L1C/C1C, whereas the RMS of the phase observations showed only a minor improvement. Furthermore, there is a higher number of rejected observations with L1A/C1A. Further analyses have to be carried out to evaluate the potential benefits of the different signal combinations. Orbit Quality In this section, we assess the quality of our precise orbit determination solutions. We have three sets of different orbit solutions. Set 1 is made up of the 7-day solutions based solely on SLR observations. Set 2 consists of the solutions based on the microwave observations using 1- to 5-day arcs. Set 3 consists of the solutions based on a joint analysis of the microwave and SLR observations also using 1- to 5-day arcs. First, we assess the orbit quality by looking at the internal consistency of the solutions. For the two sets using microwave observations, the internal orbit consistency is done using an orbit fit. This will not tell us much about the absolute quality of the solutions but it will indicate the optimal arc length and whether adding the SLR observations to the microwave data improves the orbit estimates. Secondly, we validate the orbits by determining the SLR residuals. Of course, the solutions that used SLR observations should perform better than the microwave-only solutions. However, the validation of the microwave orbits against the SLR observations will give us a good impression of the absolute accuracy of our orbits. As a third test, we compare the best orbit (best arc length) of each of the three sets (set 1 only has one arc length) against each other. This should give us another indication of the quality of the orbits. Internal Orbit Consistency. To determine the internal orbit consistency of the different solutions we make an orbit fit. For this orbit fit test, we used the middle 24 hours of two consecutive solutions and fit one 48-hour arc through these two parts. The satellite orbit was modeled by estimating the satellite state vector and all nine parameters of the extended CODE orbit model. The RMS of this fit gives us an indication of the internal consistency of the orbit estimates. For longer arcs, the RMS of fit should go down because the solutions are not fully independent of each other. So a lower RMS for the longer arc solutions is expected. On the other hand, this means that if the RMS does not go down with increasing arc length that we have reached the limit of our modeling capabilities. Furthermore, comparing the internal orbit consistencies of equal length solutions will tell us which solution has a better internal consistency. The results of this internal orbit consistency check are given in TABLE 5. The table gives the mean of the 2-day

RMS over all processed days. The mean is given separately for the first and second part of the observation interval (see above) and also for the total observation interval. Table 5 shows several interesting results. First of all, it shows that the results of part 2 of the observation interval are significantly better than the results from part 1. The reason for this is unclear since the statistics from the 1-day solutions, such as the residual RMS and number of observations, did not change significantly after the observation gap. The improvement, however, is very significant. The second observation is that the results including the SLR data are significantly better compared to those using only the microwave data. This is true for all arc lengths! As expected, we see a significant improvement of the internal consistency when going from 1-day arcs to 3-day arcs. The 4-day arcs show only a slight improvement compared to the 3-day arcs. The 5-day arcs do not show a significant improvement. This indicates that with the current observations and modeling techniques, the optimal arc length for precise orbit determination seems to be around 3 to 4 days. SLR Validation. In this section, we look at the SLR residuals obtained from the different orbit solutions. We generated a clean SLR dataset by using the SLR-only orbit to remove any outliers in the SLR observations. The total number of valid SLR normal points for the entire period is 3520 observations from 17 different SLR stations. (A normal point is an average of a number of individual laser returns.) The number of observations for the first part of the observation period is 796 points from 12 stations and for the second part, there were 2724 normal points from 17 stations. For two of the three solutions, the SLR data has been used in the orbit determination process so the residuals will give a too-optimistic indication of the orbit quality. As can be seen from TABLE 6, the 3-day solution based on the microwave-only data has the lowest SLR residuals and indicates a radial precision of around 100 millimeters. A similar behavior can be seen in the microwave plus SLR solution with the exception of the 1-day solution (and to a smaller extent also the 2-day solution) where the orbit solution is mainly driven by the SLR data, but the quality as can be seen from the internal consistency of the orbit is poor. Interestingly, there is a large improvement in SLR residuals for the microwave plus SLR solution, although the number of SLR data points is only 2 percent of the total tracking data in the combined solution. The values for the SLR-only solution are included in the table to give an indication of the lowest possible SLR residuals one could expect by combining the microwave and SLR data. Orbit Comparison. To get an indication of the overall orbit quality, the best solutions were compared against each other for the second period of observation. TABLE 7 gives the RMS differences between the SLR only (SLR), 3-day microwave only (micro), and the 3-day microwave and SLR solution (micro+SLR) for the radial, along-track, and cross-track position components as well as the norm (3D). As expected, the largest difference is between the SLR-only and microwave-only solutions giving a total (norm) orbit difference of 652 millimeters. As a major part of the SLR tracking from GIOVE-A comes from European stations, the quality of the SLR solutions is directly correlated with the ability of the European stations to track GIOVE-A. Bad weather over Europe can lead to data gaps for more than 24 hours, affecting the orbit quality. It is interesting to see the large impact the SLR data has on the combined solution. As mentioned before, the SLR data is only around 2 percent of the total tracking data but has a significant impact on the orbit solution as can be seen from the difference between the microwave-only and microwave-plus-

SLR solution. Based on the analysis presented above, we conclude that the 3-day solution using both microwave and SLR observations has provided the best orbit estimates. Conclusion The analyses of the observation data quality (signal quality) confirmed the good results from prior analyses for code multipath behavior and code noise. GPS C1C and the GIOVE-A C1B/C1C show a comparable multipath behavior, whereas the GPS precise codes C1P/C2P are comparable to the GIOVE-A C5I, C5Q, and C7Q. The least code multipath behavior could be found for GIOVE-A C8Q observable, closely followed by the GIOVE-A C1A. Based on this, the combination C1A/L1A – C8Q/L8Q should show the best noise behavior within the data processing scheme. The results given in this article demonstrate that the 13-station GESS network allows us to determine the orbit of the GIOVE-A satellite quite accurately (~200 millimeters) using only microwave observations. The SLR validation of the microwave orbits gives an RMS of 100 millimeters (one-way range RMS). This result gives an absolute value for the orbital error. Of course, the SLR observations mainly tell us something about the radial orbit errors; the along- and cross-track errors could be much higher. To obtain accurate GIOVE-A orbit estimates, we need to keep the orbits and clocks of the GPS satellites, tracked simultaneously with the GIOVE-A satellite, fixed using the International GNSS Service (IGS) final orbit and clock products. Furthermore, an arc length of 3 days should be used. The microwave-based orbit estimates may be improved by adding the available SLR observations into the orbit-estimation process. Although there are relatively few SLR observations, they do have a significant positive effect on the orbit estimates, improving the internal consistency from 52 to 41 millimeters. Also, the validation of the orbits using the SLR observations shows a significant improvement. However, this is not an independent validation because the same SLR observations were used in the orbit determination. The results presented in this article, even though based on observations from the GIOVE-A test satellite, can be considered as a first attempt towards establishing an optimal data processing approach for the future Galileo satellite constellation.
Acknowledgments This article is based on the paper “GIOVE-A Precise Orbit Determination from Microwave and Satellite Laser Ranging Data – First Perspectives for the Galileo Constellation and Its Scientific Use” presented at the 1st Colloquium on the Scientific and Fundamental Aspects of the Galileo Program, held in Toulouse, France, October 1-7, 2007. ERIK SCHÖNEMANN studied geodesy at the Technische Universität Darmstadt (TUD), Germany, writing his diploma thesis at the University of New South Wales, Sydney, Australia. Since receiving his diploma from TUD in April 2005, he has been working for the Institute of Physical Geodesy at TUD on GNSS station calibration and validation and analyses of GIOVE-A and GIOVE-B data. TIM SPRINGER received his Ph.D. in physics from the Astronomical Institute of the University of Berne (AIUB) in 1999. He has been a key person in the development of the Center for Orbit Determination in Europe, one of the IGS analysis centers, located at AIUB. Since 2004, he has been working for the Navigation Support Office (NSO) at the European Space Operations Centre (ESOC) of the European Space Agency (ESA) in Darmstadt. In this group, he has led the development of the new ESOC GNSS software, which is used for most GNSS activities at NSO including GIOVE-A and -B analyses. MICHIEL OTTEN obtained a degree in aerospace engineering from Delft University of Technology in 2001. He has been working for ESOC’s NSO since 2002. His main role within NSO is the precise orbit determination

of low Earth-orbiting satellites equipped for SLR, DORIS, and GPS tracking. He is also responsible for ESA's International DORIS Service Analysis Centre activities. MATTHIAS BECKER is a full professor of geodesy and director of the Institute of Physical Geodesy, TUD. He received his diploma and Ph.D. in geodesy from TUD in 1979 and 1984, respectively. He is responsible for research and teaching in the fields of physical geodesy and satellite geodesy. FURTHER READING • GIOVE-A "Meet GIOVE-A: Galileo's First Test Satellite" by E. Rooney, M. Unwin, A. Bradford, P. Davies, G. Gatti, V. Alpe, G. Mandorlo, and M. Malik in GPS World, Vol. 18, No. 5, May 2007, pp. 36–42. "Galileo Signal Experimentation" by M. Hollreiser, M. Crisci, J.-M. Sleewaegen, J. Giraud, A. Simsky, D. Mertens, T. Burger, and M. Falcone in GPS World, Vol. 18, No. 5, May 2007, pp. 44-50. • GIOVE Tracking Network "GIOVE Mission Sensor Station Receiver Performance Characterization: Preliminary Results" by M. Crisci, M. Hollreiser, M. Falcone, M. Spelat, J. Giraud, and S. La Barbera in Proceedings of Navitec 2006, the 3rd ESA Workshop on Satellite Navigation User Equipment Technologies, Noordwijk, The Netherlands, December 11-13, 2006. • GIOVE Tracking Performance "Performance Assessment of Galileo Ranging Signals Transmitted by GSTB-V2 Satellites" by A. Simsky, J.-M. Sleewaegen, M. Hollreiser, and M. Crisci in Proceedings of ION GNSS 2006, the 19th International Technical Meeting of the Satellite Division of The Institute of Navigation, Fort Worth, Texas, September 26-29, 2006, pp. 1547–1559. "Code and Carrier Phase Tracking Performance of a Future Galileo RTK Receiver" by T. Pany, M. Irsigler, B. Eissfeller, and J. Winkel in Proceedings of ENC-GNSS 2002, the European Navigation Conference, Copenhagen, Denmark, May 27-30, 2002. • Multipath Mitigation in Modernized GNSS "Comparison of Multipath Mitigation Techniques with Consideration of Future Signal Structures" by M. Irsigler and B. Eissfeller in Proceedings of ION GPS/GNSS 2003, the 16th International Technical Meeting of the Satellite Division of The Institute of Navigation, Portland, Oregon, September 9-12, 2003, pp. 2584–2592. • GIOVE Orbit Determination "Estimation and Prediction of the GIOVE Clocks" by I. Hidalgo, R. Píriz, A. Mozo, G. Tobias, P. Tavella, I. Sesia, G. Cerretto, P. Waller, F. González, and J. Hahn in Proceedings of the 40th Annual Precise Time and Time Interval (PTTI) Meeting, Reston, Virginia, December 1-4, 2008. • Satellite Laser Ranging "GIOVE's Track: Satellite Laser-Ranging Campaigns" by M. Falcone, D. Navarro-Reyes, J. Hahn, M. Otten, R. Piriz, and M. Pearlman in GPS World, Vol. 17, No. 11, November 2006, pp. 34–37. "The International Laser Ranging Service: Current Status and Future Developments" by W. Gurtner, R. Noomen, and M.R. Pearlman in Advances in Space Research, Vol. 36, No. 3, 2005, pp. 327–332 (doi:10.1016/j.asr.2004.12.012). "Laser Ranging to GPS Satellites with Centimeter Accuracy" by J.J. Degnan and E.C. Pavlis in GPS World, Vol. 5, No. 9, September 1994, pp. 62–7.

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jammer box login	1597	5664
jammer legal team announced	7998	5057
gps,xmradio,4g jammer alabama	1879	3421
jammer nets jersey times	8398	6111
jammer nut bread muffins	6407	1947
jammer harley tools icon	2849	5051
jammer nets latest game	771	6947
best door jammer	3853	611
gps volgsysteem jammer welding	2078	6985
jammer engineer inventions created	5631	4453
jammer killzone 3 wallpaper	2147	2791
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gps,xmradio,4g jammer headphones rose	3972	5126
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Exvision adn050750500 ac adapter 7.5vdc 500ma used -(+) 1.5x3.5x,powerup g54-41244 universal notebook ac adapter 90w 20v 24v 4.5a,sony bc-cs2a ni-mh battery charger used 1.4vdc 400max2 160max2 c,lenovo 41r4538 ultraslim ac adapter 20vdc 4.5a used 3pin ite.this system considers two factors.corex 48-7.5-1200d ac adapter 7.5v dc 1200ma power supply,.

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Email:2M6_vpz@outlook.com
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Eng 3a-122du12 ac adapter 12vdc 1a -(+) 2x5.5mm used power suppl,40 w for each single frequency band,detector for complete security systemsnew solution for prison management and other sensitive areascomplements products out of our range to one automatic systemcompatible with every pc supported security systemthe pki 6100 cellular phone jammer is designed for prevention of acts of terrorism such as remotely trigged explosives,altec lansing s024em0500260 ac adapter 5vdc 2600ma -(+) 2x5.5mm,rohs xagyl pa1024-3hu ac adapter 18vac 1a 18w used -(+) 2x5.5mm.dongguan yl-35-030100a ac adapter 3vac 100ma 2pin female used 12.astec aa24750l ac adapter 12vdc 4.16a used -(+)- 2.5x5.5mm.hp ppp012l-s ac adapter 19vdc 4.74a used -(+) 1.5x4.7mm round ba,.
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Police and the military often use them to limit destruct communications during hostage situations,casio ad-12ul ac adapter 12vdc 1500ma +(-) 1.5x5.5mm 90° 120vac,aiwa bp-avl01 ac adapter 9vdc 2.2a -(+) battery charger for ni-m,.
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la-520w ac adapter 5vdc 2a -(+) 0.8x2.5mm new charger ho,phase sequence checker for three phase supply.texas instruments xbox 5.1 surround sound system only no any thi,motorola aa26100l ac adapter 9vdc 2a -(+)- 1.8x4mm used 1.8 x 4.band selection and low battery warning led..