Tracking Operations During the Voyager 2 Launch Phase

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The Voyager 2 launch phase tracking operational procedures were carefully studied and conservatively designed to accommodate any launch contingency. This launch phase was marked by the first use of the Goldstone complex, including the 64 meter antenna, as the initial acquisition location. The following report details the pre-launch planning for and subsequent analysis of tracking operations during the Voyager 2 launch phase.

I. Introduction

On August 20, 1977 at 14:29:44.27 Greenwich Mean Time (GMT), Voyager 2 lifted off from the Kennedy Space Center signaling the somewhat unsure start of the Voyager mission. The purpose of this mission is to study the regions of Jupiter, Saturn, and possibly Uranus, as well as the interplanetary media.

To begin this investigation, Voyager 2 was launched at an azimuth of 124.09 degrees aboard a Titan 3E/Centaur D1T launch vehicle with insertion into the trans-Jupiter orbit occurring over Southeast Asia. The geometry of the parking orbit and subsequent Jupiter transfer orbit was such that the Goldstone Deep Space Communications Complex, specifically Deep Space Station (DSS) 12, became the prime initial acquisition station. This launch marked the first use of a Goldstone station for the initial acquisition as well as the first use of a 64 meter station during the initial pass.

This report details the pre-launch planning for the initial acquisition pass and presents an analysis of the events of that pass.

II. Trajectory Considerations

The open window launch trajectory for 20 August presented angle and frequency rates which were comparable to other recent parking orbit ascent launches (Ref. 1). Specifically, these rates were:

$$\text{Hour Angle (HA)} = -0.049 \text{ degrees/second}$$
$$\text{One Way Doppler (D1)} = +82.6 \text{ Hz/second}$$
$$\text{XA} = 68 \text{ Hz/second (S-Band)}$$

The trajectory for Voyager 2 also had the following characteristics:

(1) The angle and frequency rates were highest at open window of any particular launch date

(2) The highest maximum elevation angle was achieved for open window launch

(3) The declination of the spacecraft was very high (41°) and would remain so for many weeks after launch

Of these three items, only the high declination angle required special planning which is detailed in Section VII.

Figure 1 stereographically illustrates the initial pass over DSS 12 while Figure 2 depicts the elevation angle during this pass. Additionally, Figure 2 serves as a timeline for significant tracking events that occurred during the pass.

An important facet in the design of an initial acquisition strategy is the effect of an anominal launch in the spacecraft trajectory. To this end, 3σ launch trajectories were provided by the Voyager Navigation team. Examination of these trajectories yielded the following 3σ uncertainties in the tracking parameters at the rise of DSS 12:

3σ Hour Angle = 0.31 degrees

3σ D1 = 300 Hz (S-Band)

3σ D2 = 600 Hz (S-Band)

3σ XA = 182 Hz (S-Band)

These figures are somewhat smaller than those encountered in other recent launch phases. For example, for the Helios 2 launch (Ref. 2) the 3σ uncertainties were:

3σ Hour Angle = 1.15 degrees

3σ D1 = 3500 Hz (S-Band)

3σ XA = 1632 Hz (S-Band)

These data were, however, somewhat incomplete in that there exist many different possibilities for non-standard trajectories which could result in (possibly) larger errors. In light of this and in order to insure complete success, the initial acquisition strategy was developed from an extremely conservative approach.

III. Tracking Subsystem Software

This launch, unlike any other launch, was to be supported using a plethora of newly implemented software as well as much new hardware. Since the last (Helios 2) launch, new Antenna Pointing Subsystem (APS) and Planetary Ranging Assembly (PRA) software had been implemented, the tracking prediction software had been extensively changed, the Metric Data Assembly (MDA) and its associated software had been newly implemented and the Block III Network Support Controller (NSC) had come into use. As this software and equipment underwent extensive pre-launch testing, many flaws and failures were discovered; in fact, every one of the above mentioned components underwent some degree of modification during the last few months before launch.

A. Tracking Predictions

In March of 1977, the DSN tracking prediction system was completely changed. The previous system relied wholly on topocentric trajectory data in the form of a polynomial coefficient tape (PCT) generated by the project navigation team. This PCT was then evaluated by the PREDIK software to produce tracking predictions.

The new (and currently used) system requires as input a probe ephemeris tape (PET) containing the probe trajectory in terms of a central body. The PET then becomes the input to the Fast Phi-factor Generator Program (FPGP) which translates these data to topocentric observables and generates the PCT input to PREDIK.

In the course of generating the many predicts sets required to characterize the launch trajectories, it was found that FPGP could not quickly or accurately produce launch phase predictions. These problems obviously caused concern that FPGP could not be used at all during the launch phase of Voyager. To improve the running time of FPGP there were extensive changes to the program files. These changes resulted in the elimination of two tapes and much operator intervention. This streamlining allowed the running time to be reduced significantly.

It was also discovered that FPGP tended to over fit when the observables were undergoing a high rate of change. To correct this situation FPGP was modified to allow user control of the minimum span duration thereby diminishing the tendency toward overfitting.

In later testing (in fact, within three weeks of launch), it was found that the time from launch (TFL) option did not function correctly. While copies of the predicts produced at JPL had the proper time field, those received at the stations did not. Since this was an important launch phase predicts option, (see Section IV) the cause of the problem (one line of the program had been inadvertently omitted) was quickly isolated and corrected.

The NSC is the $\Sigma 5$ computer used to generate and transmit tracking and telemetry predictions as well as other products such as the sequence of events and schedule. During pre-launch testing it was found that the NSC software used in the construction of transmission files would not accept the Voyager spacecraft identifiers. It was also discovered during the testing cycle that the Metric Data Assembly (MDA) would not permit reception of a single pass of predictions. During the launch phase predictions are, of course, generated on a single pass basis. Both programs were quickly modified to correct these anomalies.

Thus, after a less than encouraging start, the prediction system was finally ready for launch support with less than three weeks to spare.

B. APS II Drive Tape Verification

With the implementation of the APS II software in early 1976, the format of the antenna drive tape was changed thereby nullifying the drive tape verification software. This left only a check sum computation for verification of the drive tape. It was believed that this method of verification was wholly inadequate for support during this critical phase. The original APS drive tape verification program was therefore quickly modified and brought into operational usage just weeks before the Voyager 2 launch.

C. Planetary Ranging Assembly

In late May analysis of ranging data from DSS 12 revealed a one second error in the range acquisition (T_0) time as reported by the MDS version of the Planetary Ranging Assembly (PRA) software. Like the other previously discussed problems, this one was quickly corrected and the PRA was made ready for launch support.

IV. Angle Drive Strategy

The angle drive strategy for the Voyager 2 was essentially the same strategy successfully used during previous launches and was based upon the following considerations:

(1) It was desired that the uplink be acquired shortly after rise,

(2) Usage of a drive tape was required during the one-way to two-way transition,

(3) Acquisition of early (near earth) auto track data was desired, and

(4) It was desired to lock the receiver coupled to the S-Band Cassegrain antenna as well as the S-Band Acquisition Aid Antenna (SAA) connected receiver prior to initiation of the uplink sweep.

It was planned that at least four and possibly five drive tapes would be generated to assure the station of the best available drive tape. The antenna drive strategy then became:

(1) At launch minus seven days (or L-24 hours if the launch date slipped) open, mid and close window drive tapes were to be generated. These tapes would be in TFL format and would be used as back ups for drive tapes to be produced during the final countdown. To use these tapes, a time offset (Δt) equal to the actual lift-off time would be entered into the APS. Which tape to use would be specified by the Tracking Network Operations Analyst (NOA).

(2) At L-105 minutes a new drive tape with times in GMT format would be generated. It had been determined previously that (based upon an analysis of angle rates) the SCM antenna beam width would tolerate an error of up to three seconds in lift-off time before it would become extremely difficult to lock the receivers. The L-105 minute predicts would then be prime if launch was within three seconds of expected.

(3) At L-4 minutes, a contingency predicts set based upon a lift-off plus three second trajectory would be generated. If lift-off was more than three seconds late, these predicts would be transmitted to the station for use in punching a drive tape.

(4) Finally, if none of the previously mentioned drive tapes were adequate, a prediction set based on the actual lift-off time would be generated as soon as that time became known. A drive tape based on these predictions would become prime.

Following the uplink acquisition, as early as practicable the antenna drive mode would be changed to auto track. This switch would be done in three steps: the signal on the SAA receiver would be peaked using offsets to the latest available drive tape, auto track would then be accomplished on the SAA, and finally, auto track would be accomplished on the SCM.

V. Initial Uplink Acquisition

The Voyager initial uplink acquisition had been designed with the following criteria in mind:

(1) The uplink should be acquired at the earliest practicable time based on station capabilities and spacecraft trajectory constraints,

(2) The uplink acquisition sweep should span a frequency range and be at a rate that best guarantees acquisition on the first sweep, and

(3) The uplink acquisition should be complete in time to have all stations (particularly DSS 14) ready to receive the critical 7.2 kbps telemetry data.

The following uncertainty information pertaining to the uplink was made available by the Voyager project:

3σ Trajectory	~ 192 Hz (S-Band)
3σ Measurement	~ 1000 Hz (S-Band)
3σ Receiver "Random Walk"	~ 2000 Hz (S-Band)
3σ S/C Temperature	~ 1500 Hz (S-Band)

Combining the above, one arrives at a total 3σ uncertainty of:

3σ Total	~ 2700 Hz (S-Band)
or	~ 28 Hz (VCO)

This uncertainty was extremely small with respect to uncertainties for previous missions (for instance 3σ for Viking was 5300 Hz), therefore, to be extremely conservative (and hence allow for any sort of abnormal launch vehicle or spacecraft performance) and since there was no real impact on tuning duration, the previously described 3σ uncertainty was more than tripled resulting in a sweep of approximately XA ± 9600 Hz (S-Band) or XA ± 100 Hz (VCO).

The Voyager spacecraft receiver tuning rates are bounded by:

$$60 \text{ Hz/sec} < \text{tuning rate} < 1000 \text{ Hz/sec (S-Band)}$$

$$(\text{or } 0.6 \text{ Hz/sec} < \text{tuning rate} < 10 \text{ Hz/sec (VCO)})$$

under the strong signal (−100 dBm) conditions that were to be encountered during the initial pass. For the initial acquisition a sweep rate of 3 Hz/sec (VCO; or 288 Hz/sec at S-Band level) was selected because:

(1) The rate was well above the push limit of the receiver and thus would result in a successful acquisition.

(2) Should it become necessary to manually tune the exciter, it was believed that the station could not accurately tune at a higher rate than the chosen rate.

(3) A rate of 288 Hz/sec (S-Band) would result in an effective (Doppler rates considered) tuning rate of approximately 238 Hz/sec at the spacecraft receiver. This rate was very nearly the geometric mean of the upper and lower sweep rate limits (245 Hz/sec).

The sweep was to start at lift-off plus 78 minutes, approximately 5 minutes after the spacecraft would have risen. This allowed sufficient time for the necessary sideband/sidelobe searches before starting the uplink acquisition.

Finally, the sweep was to consist of a single upleg in the direction of the change of XA, with the ending frequency becoming the TSF for the remainder of the pass. This was advantageous in that no additional tuning to reduce static phase error (SPE) would be required during the remainder of the pass.

Incorporating the preceding information, the general uplink acquisition procedure was:

(1) Transmitter connected to the S-Band Acquisition Aid Antenna (SAA) and set to radiate at 10 kw.

(2) Transmitter on at start of uplink sweep minus 20 seconds.

(3) Radiometric data to be flagged two way at start of sweep minus 10 seconds. (This would enable the NOCT to know when (and if) two-way lock was achieved and whether lock was on the main carrier or a sideband.)

(4) Sweep to start at L+78 minutes or approximately 5 minutes after spacecraft rise.

(5) Sweep to cover at least XA ± 100 Hz (VCO) at a rate of 3 Hz/sec (VCO).

(6) Sweep duration to be approximately 80 seconds.

If the first sweep failed a contingency sweep encompassing a region 50 percent larger (XA ± 150 Hz (VCO)) than the original sweep would be performed, starting 2 minutes and 30 seconds after completion of the first sweep. The contingency sweep would consist of a downleg and an upleg followed by a sweep back to TSF executed continuously with no pauses between legs. (Of course, if two-way was achieved anytime during the contingency sweep the station was to stop tuning, lock the receivers and then tune directly to TSF.) The tuning instructions for both sweeps were to be provided to DSS 12 well before lift-off via a sweep message similar to that shown in Fig. 3.

VI. Ranging

Range data collection for Voyager was to begin shortly after the initial acquisition at DSS 12. Additionally, plans were made to transfer the uplink from DSS 12 to DSS 14 so that ranging could continue for as long as possible.

Originally, it had been planned that the ranging would be done with eighteen component acquisitions interspersed with ten component acquisitions. After the risks inherent in changing range parameters (i.e., possibly significant losses of data) were pointed out to the Voyager project, it was decided to pipeline fifteen component ranging acquisitions separated by three differenced range versus integrated doppler (DRVID) measurements.

The following parameters were to be used:

(1) T1 = 59 seconds

(2) T2 = 2 seconds

(3) T3 = 60 seconds

(4) T0 = 3CCEE

(5) RTLT = 0 seconds

(6) Number of components = 15

(7) Carrier Suppression = 3 dB

VII. Downlink Acquisition at DSS 62

Because of the high declination (41°) of the Voyager 2 trajectory, it was found that DSS 62 would be unable to acquire the spacecraft downlink until the spacecraft reached an elevation of approximately 16°, this being the minimum elevation at which the antenna could be pointed at this declination. On the first pass, this constraint would cause a more than fifty minute gap between the end of track at DSS 44 and the start of track at DSS 62. However, because of the strong signal levels expected during that time, it would be possible to narrow the gap considerably using the SAA. From available information, the threshold of the SAA was computed to be:

-164.4 dBm in the 48 Hz RF Bandwidth

-170.4 dBm in the 12 Hz RF Bandwidth

The signal level at the time of DSS 44 set was expected to be at least -161.4 dBm. Thus, there would be from three to nine decibels of downlink margin. From (very old!) SAA antenna patterns it was found that the angular offsets necessary to reduce the signal level to threshold were:

~8° for threshold in the 48 Hz RF Bandwidth

~15° for threshold in the 12 Hz RF Bandwidth

These offsets translated (assuming sidereal angle rates) to an increase of from 32 to 61 minutes in the view period of DSS 62. Thus, the obvious conclusion was that, by judicious use of the receiver, the downlink could be acquired using the broad (16°) beam of the SAA and at a much lower elevation than that at which the main antenna could even point, thereby reducing the gap in the tracking of the spacecraft and possibly eliminating it completely. The extended coverage is stereographically illustrated in Fig. 4.

It was decided to attempt to close the downlink gap (the gap in the uplink would be tolerated) using the following procedure:

(1) Two sets of predicts would be generated for DSS 62. One set, to be used for driving the antenna, would have the actual horizon mask. The other set would have a zero degree elevation horizon and would be used to compute frequencies for the SAA receiver sweep.

(2) DSS 62 would drive to the specified rise point (as defined by the antenna limits) at least by the time that the spacecraft would reach zero degrees elevation.

(3) At the time of the earliest possible acquisition, DSS 62 personnel would slowly sweep the receiver in the 12 Hz RF bandwidth and attempt to acquire the downlink.

(4) When the spacecraft reached the rise point the SCM receiver would be locked and normal tracking, including an uplink acquisition, would begin.

The coverage gap would continue for several weeks after launch but, unfortunately, this use of the SAA would be restricted to (because of signal level constraints) the first pass.

VIII. Post Launch Analysis

A. Tracking Predictions

1. Prediction Generation. Minutes before the scheduled 14:25:00 GMT lift-off time the Voyager 2 countdown went into a hold that was to last four minutes and 44 seconds. This delay made it imperative that tracking predictions based on the actual lift-off time be generated and made available to the initial acquisition stations prior to spacecraft rise, approximately 70 minutes after launch.

Because of the suddenness with which the hold was initiated and terminated, there was much confusion about what the actual lift-off time was to be. This confusion resulted in the required lift-off PET being delivered approximately fifteen minutes after lift-off.

Thanks in large part to the pre-launch streamlining (Section IIIA), predicts were available approximately twenty minutes before the expected spacecraft rise.

2. Prediction Accuracy. The accuracy of the launch phase predictions (as measured by pseudo-residuals) was very good. The pseudo-residuals, computed in near real-time by differencing radiometric data with the lift-off tracking predictions in the NOCC Tracking Real Time Monitor (RTM), had the following average values during the early portions of the launch pass at DSS 12:

$\Delta HA \cong -0.085$ degrees

$\Delta D2 \cong -130$ Hz (S-Band)

$\Delta XA \cong 8.9$ Hz (VCO)

These differences may be compared to the 3σ uncertainties presented in Sections II and V:

$3\sigma\ \Delta HA \cong 0.309$ degrees

$3\sigma\ \Delta D2 \cong 588$ Hz (S-Band)

$3\sigma\ \Delta XA \cong 30$ Hz (VCO)

As can be seen, all residuals were well within the 3σ uncertainties. The small Hour Angle residual was especially significant in that it facilitated the spacecraft acquisition at DSS 14 by being less than the beamwidth of the 64 meter antenna.

The two way doppler residual continued to increase throughout the pass attaining a value of approximately -169 Hz (S-Band) late in the pass at DSS 12.

The value of the ΔXA was very small considering the many possible sources of error, both trajectory and temperature. The 3σ uncertainty provided by Voyager telecom was thus shown to be very accurate.

B. Initial Downlink Acquisition

The initial downlink acquisition at DSS 12 proceeded very smoothly with acquisition occurring at 15:41:31 GMT or approximately one minute before the expected spacecraft rise time. As can be seen in Figure 5, the receiver was swept through a very wide (approximately 12 KHz) range of frequencies apparently centered at the downlink frequency expected at spacecraft rise and commencing well before rise.

The early acquisition is due to the fact that because of the high declination angle, spacecraft rise was dictated by the antenna mechanical limits (see Figure 1) rather than the local horizon. Thus, it was possible for the SAA to "see" the spacecraft below the antenna limits. Additionally, because of the high signal levels present during this phase it was possible to lock the SCM receiver as the spacecraft passed through the sidelobes of the SCM antenna resulting in acquisition approximately 40 seconds earlier than planned.

C. Initial Two-Way Acquisition at DSS 12

Shortly after lift-off an apparent problem with the spacecraft inertial reference unit gyros was detected by the project. Because of the nature of the problem (the attitude control computer had changed gyro pairs several times), project requested that the DSN acquire the uplink at the earliest possible time to allow for emergency commanding, if it became necessary. Since the initial uplink sweep had already been designed to start at the earliest possible time (see Section V) it was decided not to depart from the current (familiar) plan.

The uplink acquisition parameters provided to DSS 12 were:

(1) Transmitter on:	15:47:40	GMT
(2) Transmitter power:	10	KW
(3) Frequency:	22014140.0	Hz (VCO)
(4) Start tuning:	15:48:00	GMT
(5) Tuning rate:	180	Hz/min (VCO)
(6) Tune to:	22014380.0	Hz (VCO)

A comparison of the instructed sweep with the sweep actually performed at DSS 12 is shown in Figure 6. As can be seen, the sweep was performed excellently and closely followed the expected tuning pattern.

The spacecraft receiver was acquired at 15:48:36 GMT, within 10 seconds of the expected time.

The acquisition of the two way downlink did not, unfortunately, proceed as smoothly as that of the uplink. The receiver was quickly relocked (in about 3 seconds) to the coherent downlink. It was soon noticed that the doppler residuals were larger than expected (almost six times the 3σ magnitude) and changing very quickly (see Table 1 and Figure 7).

At 15:49:57 GMT, receiver lock was broken and a sideband search performed. Upon reacquisition of the downlink the doppler residuals showed that the receiver had again locked to a spurious signal. This time, however, the doppler residuals indicated a positive bias but with the same magnitude as those calculated before the sideband search. Additionally, the signal was very noisy with doppler noise averaging more than 11 Hz.

At approximately 16:00:00 GMT, DSS 12 was instructed to perform yet another sideband search. During this search the receiver was swept through a frequency range of approximately 170 KHz (S-Band level) around the expected carrier. When the receiver was relocked at 16:00:30 GMT, the carrier was finally acquired as indicated by a doppler residual of approximately -130 Hz and doppler noise of approximately 0.030 Hz.

The cause of the spurious signals has not been precisely determined. However, it is believed that since:

(1) No other station experienced the same problem

(2) The spurious signals were spaced evenly (approximately 4 KHz) on both sides of the expected carrier frequency

(3) The station reported that they returned to the original frequency after the sideband search

the spurious signals may have been an artifact of the effect of the high signal level on the DSS 12 receiver.

D. Angle Tracking

In accordance with the plan outlined in Section IV, tracking predictions based on the actual lift-off time were generated and transmitted to DSS 12 prior to the expected spacecraft rise time. These predictions were in turn used in the generation of the antenna drive tape used by DSS 12 during the early portion of its pass.

At 15:49:27 GMT, immediately following the completion of the two-way acquisition, DSS 12 went to auto track. However, partly because of the receiver lock on the erroneous frequency, the antenna quickly drifted off point driving a maximum of two degrees from the predicted pointing angle. At 15:49:57 GMT DSS 12 returned to aided track.

After locking to the carrier, the drive mode was returned to auto track successfully at 16:02:21 GMT.

Because of a change in the attitude of the spacecraft DSS 12 returned to aided track shortly after 17:11:00 GMT when the signal level fell below the auto track threshold. The station continued to track in this mode for the remainder of the pass.

E. Ranging at DSS 12

Ranging data at DSS 12 was found to be invalid shortly after the ranging sequence was started. Several unsuccessful attempts were made to locate and correct the problem but no obvious problem could be found during the pass.

Later, extensive investigation revealed that the fault was in the rate-aiding circuitry of the Planetary Ranging Assembly and was therefore not detectable in the testing configuration used during the initial Voyager 2 pass.

The loss in ranging data from DSS 12 was somewhat compensated for by the short period of ranging at DSS 14.

F. Summary of Events at DSS 14

DSS 14 became the first 64 meter station to acquire the Voyager spacecraft at 15:41:52 GMT, within 20 seconds of the acquisition by DSS 12. The ease of the lock-up allayed fears that, because of the narrow beamwidth of the antenna and the large uncertainties in the near earth trajectory, DSS 14 would not acquire in time to receive the high rate (7.2 KB/s) telemetry data.

Due to an error in entering the correct subcarrier demodulator assembly (SDA) frequency during the generation of the tracking predictions, the major portion of this data was lost. DSS 14 was able to lock the SDA after approximately 28 minutes after discovering a 40 KHz error in the frequency. During the data outage at DSS 14, the MIL 71 tracking station provided the high rate telemetry data.

Following the transfer of the uplink from DSS 12, DSS 14 began ranging at 19:47:00 GMT. The ranging data was good and provided the project with important near earth data.

DSS 14 continued tracking until 22:05:00 GMT.

G. Downlink Acquisition at DSS 62

The attempt to close the downlink gap between DSS 44 and DSS 62 by using the SAA met with only marginal success. During the Titan burn, the spacecraft switched to its secondary attitude control processor. Because of this unexpected change, the project decided to delay the acquisition of the stellar reference, Canopus, until the contents of the processor could be examined. This decision left the spacecraft in a less than optimum attitude. The resultant degradation in signal level severely impacted the "off point" tracking scheme described in Section VII.

The antenna at DSS 62 was driven to the antenna mechanical prelimits well before the expected time of spacecraft rise. At 22:57:00 GMT, approximately five minutes earlier than expected, the downlink signal was detected but at too low a level to maintain receiver lock. Continuous receiver lock was finally achieved at 23:27:00 GMT but at a signal level (-170 dBm) well below telemetry threshold. At the time of continuous receiver lock, the spacecraft was still nine degrees away from the main beam of the SCM antenna. Because of the unfavorable attitude of the spacecraft, telemetry was not received until the SCM receiver could be locked at 00:02:00 GMT.

It is apparent, then, that had the spacecraft been aligned as planned, the SAA could have been successfully used to close the gap between DSS 44 and DSS 62.

IX. Conclusion

The Voyager 2 launch and near earth phases were marked by spacecraft and data acquisition problems resulting in an inauspicious beginning for the Voyager mission.

The DSN tracking procedures and in particular the initial acquisition procedures, having been conservatively designed to encompass any launch contingency, significantly contributed to the successful completion of this phase of the Voyager mission.

References

1. Berman, A.L. and J.A. Wackley, "Tracking Operations During the Viking 1 Launch Phase," in *The Deep Space Network Progress Report,* 42-30, pp. 273-290, Jet Propulsion Laboratory, Pasadena, Calif., December 15, 1975.

2. Bright, L.E., "Tracking Operations During the Helios 2 Launch Phase," in *The Deep Space Network Progress Report,* 42-32, pp. 277-295, Jet Propulsion Laboratory, Pasadena, Calif., April 15, 1976.

Table 1. DSS 12 doppler residuals

GMT	Doppler Residual, Hz	Comment
15:47:29	+1077.1	Last good one-way residual
15:48:00	−11947.7	Start uplink tuning
15:48:36	−1571.8	Two-way uplink acquired
15:48:37	−1958.9	Receiver out of lock
15:49:25	−3325.1	Tuning completed; in lock on spurious signal
15:49:46	−3499.9	In lock on spurious signal
15:50:05	−14533.9	Sideband search; maximum excursion
15:50:33	+3192.6	Receiver in lock on spurious signal following first sideband search
15:52:00	+3025.8	Still on spurious signal
15:54:00	+2976.7	Still on spurious signal
15:56:00	+2944.5	Still on spurious signal
15:58:00	+2909.2	Still on spurious signal
16:00:01	−9789.1	Start second sideband search
16:00:06	−162635.9	Maximum negative excursion
16:00:17	+172736	Maximum positive excursion
16:00:29	−130.5	Receiver in lock on carrier
16:01:00	−134.3	Receiver in lock on carrier
16:03:00	−145.4	Receiver in lock on carrier

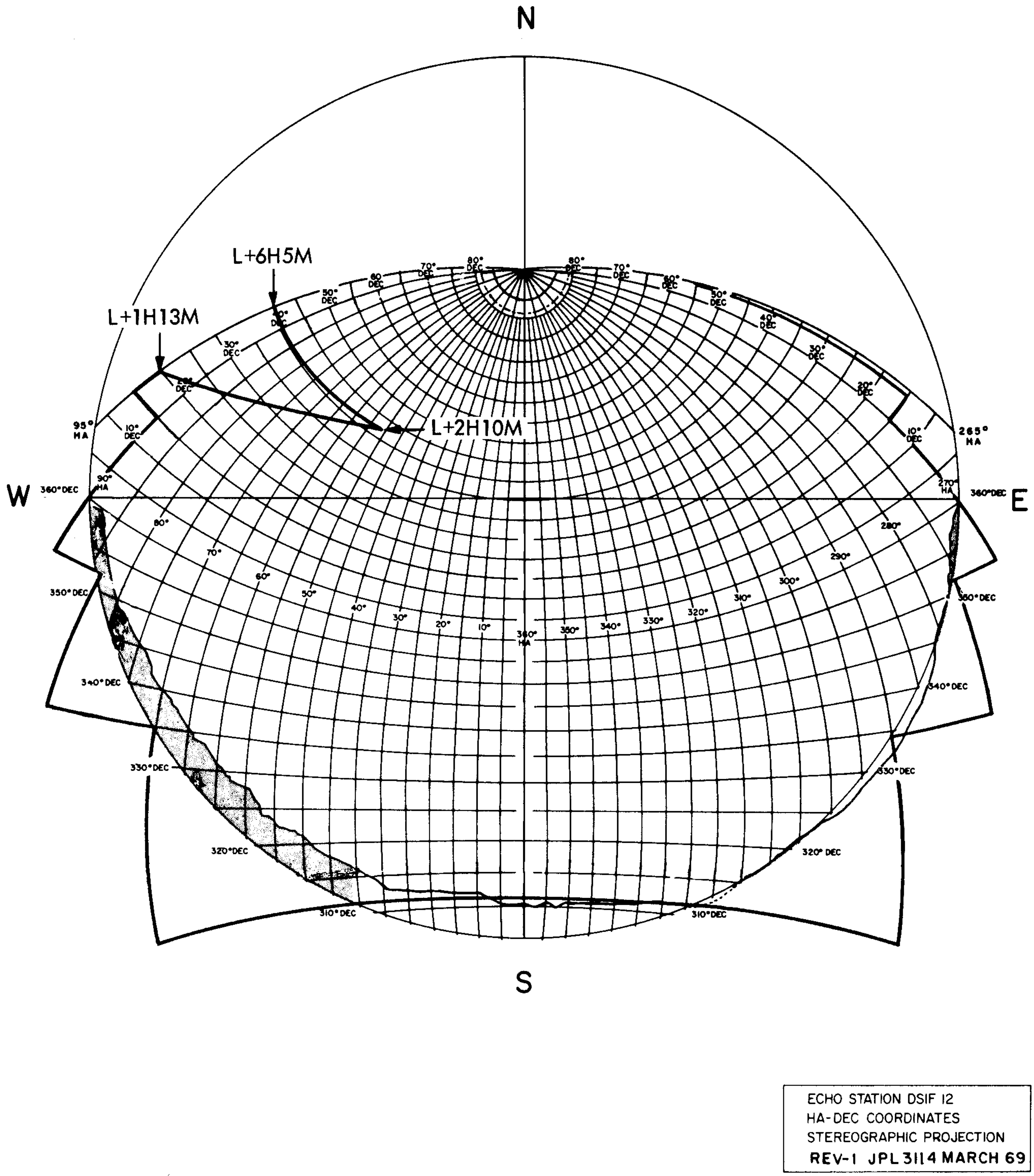

Fig. 1. DSS 12 Voyager 2 launch, 20 August 1977

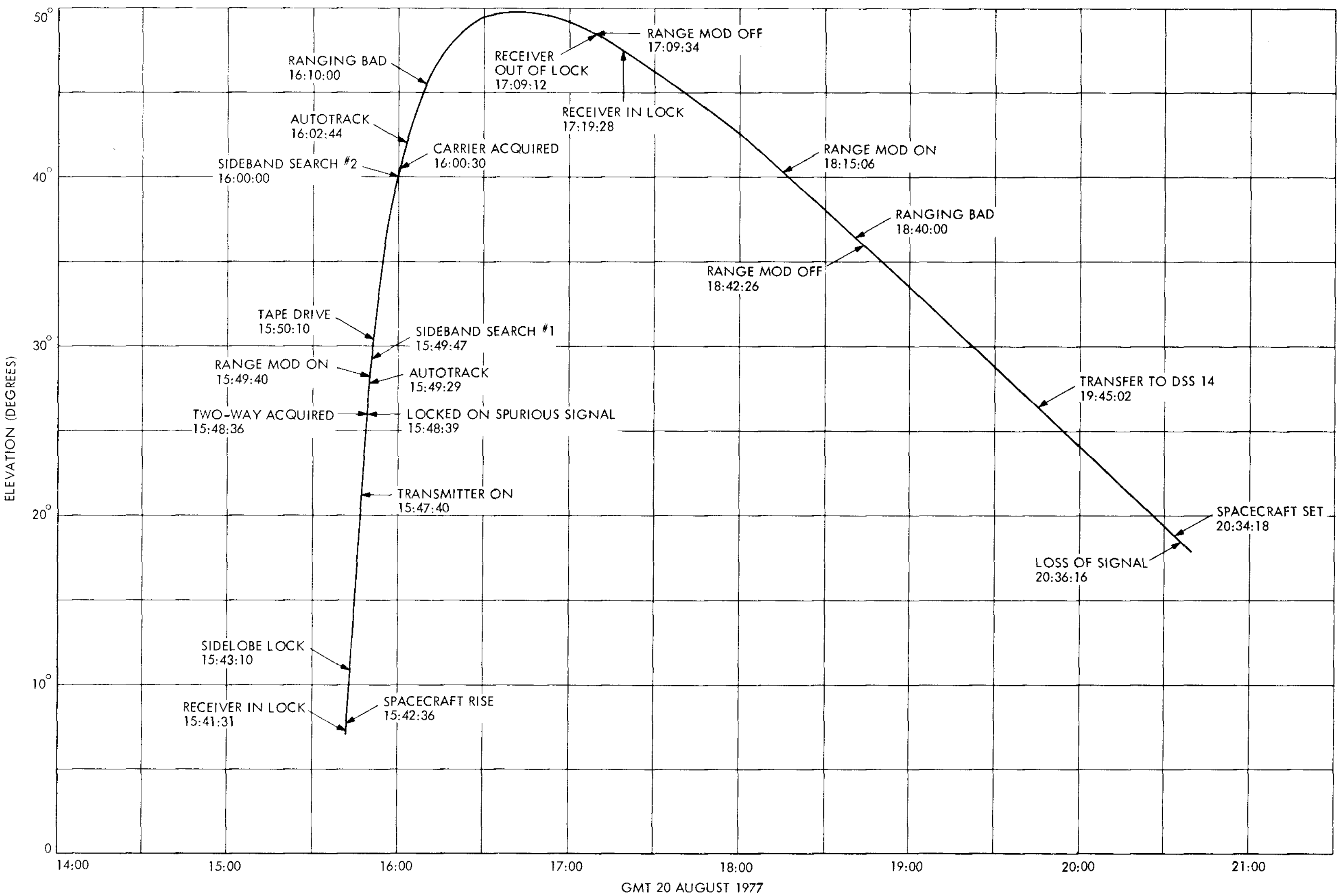

Fig. 2. Spacecraft elevation at DSS 12, Voyager 2 launch

VOYAGER 2 INITIAL ACQUISITION DSS-12 VERSION 3

A. PREDICTS			
1. TEXT:	X205		IS PRIME
2. DRIVE TAPE:	X205		IS PRIME
3. HA BIAS:	—		DEG
4. DEC BIAS:	—		DEG
5. MAX HA RATE:	−2.84	DEG/MIN AT 15:42:48	GMT
6. MAX DEC RATE:	+2.17	DEG/MIN AT 15:42:48	GMT
7. APS TIME BIAS:	— H	— M	— S
B. INITIAL UPLINK ACQUISITION			
8. TXR ON:	15:47:40		GMT
9. TXR PWR:	10		KW
10. TSF 1:	22014140.0		HZ
11. START TUNING:	15:48:00		GMT
12. TUNING RATE:	+180		HZ/MIN (VCO)
13. TSF 2:	22014380.0		HZ
14. CMD MOD ON:	15:49:30		GMT
15. RNG MOD ON:	15:49:40		GMT

* *

C. CONTINGENCY SWEEP: EXECUTE ONLY IF DIRECTED		
16. START TUNING:	15:52:00	GMT
17. TUNING RATE:	180	HZ/MIN (VCO)
18. SWEEP DOWN TO:	22014180.0	HZ
19. SWEEP UP TO:	22014500.0	HZ
20. SWEEP DOWN TO TSF:	22014380.0	HZ
21. CMD MOD ON:	15:51:00	GMT

* *

D. RANGING PARAMETERS

TO: 3CCEE T1: 59 T2: 2 T3: 60

RTLT: 0 COMPONENTS: 15

SPECIAL INSTRUCTIONS: CARRIER SUPPRESSION = 3 dB

Fig. 3. Actual uplink acquisition message, Voyager 2 launch

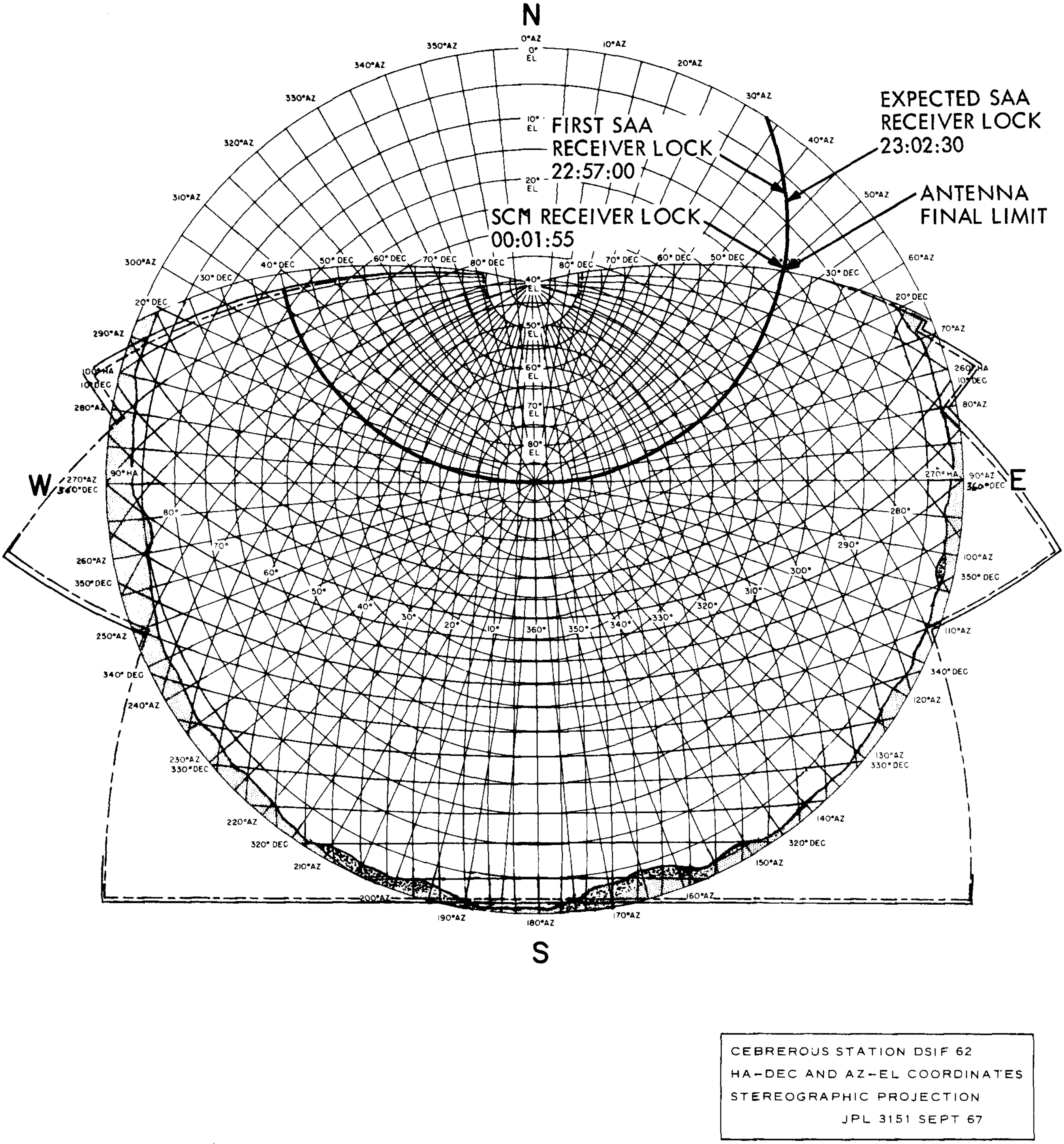

Fig. 4. DSS 62 Voyager 2 launch, 21 August 1977

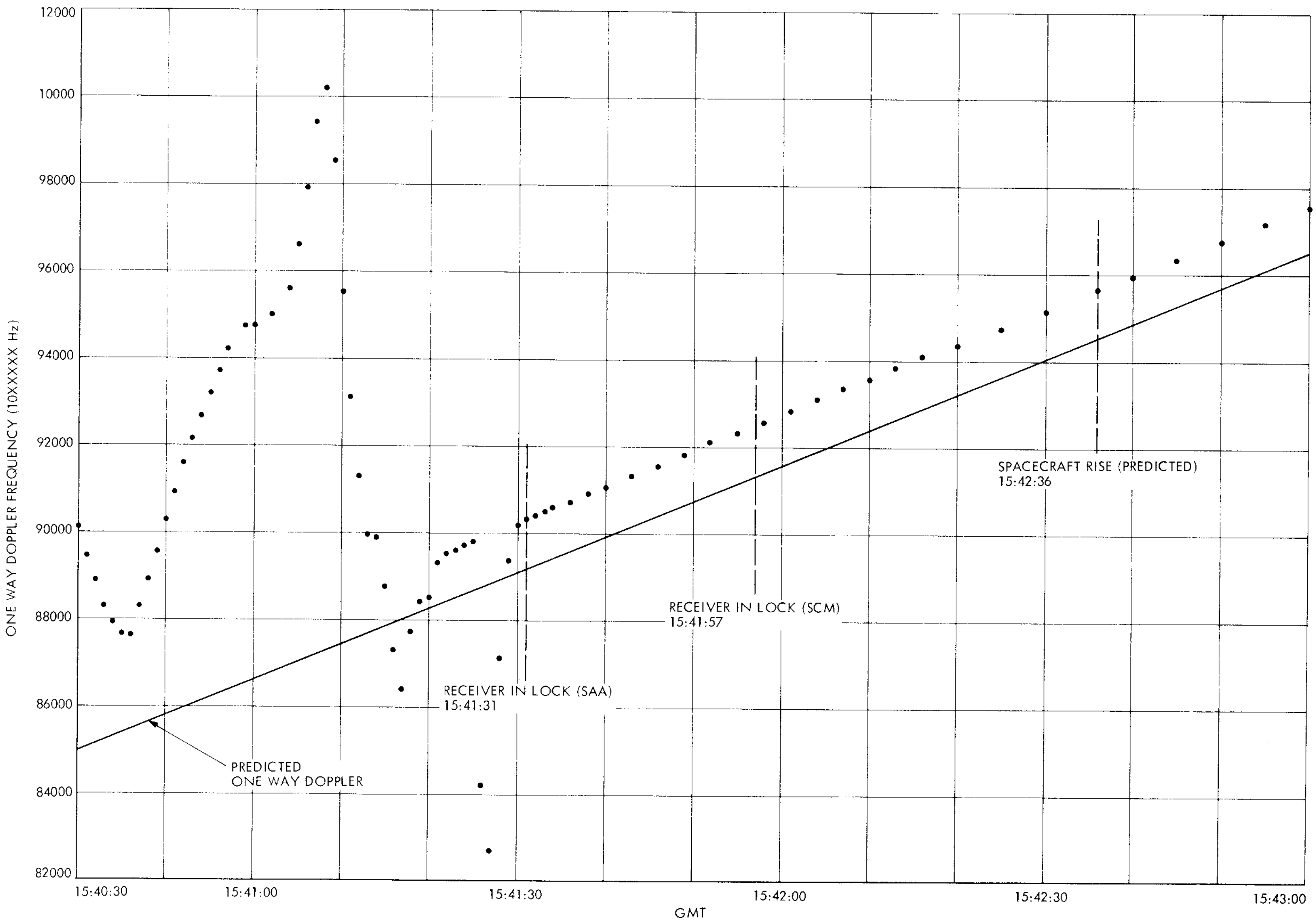

Fig. 5. Initial downlink acquisition at DSS 12, Voyager 2 launch

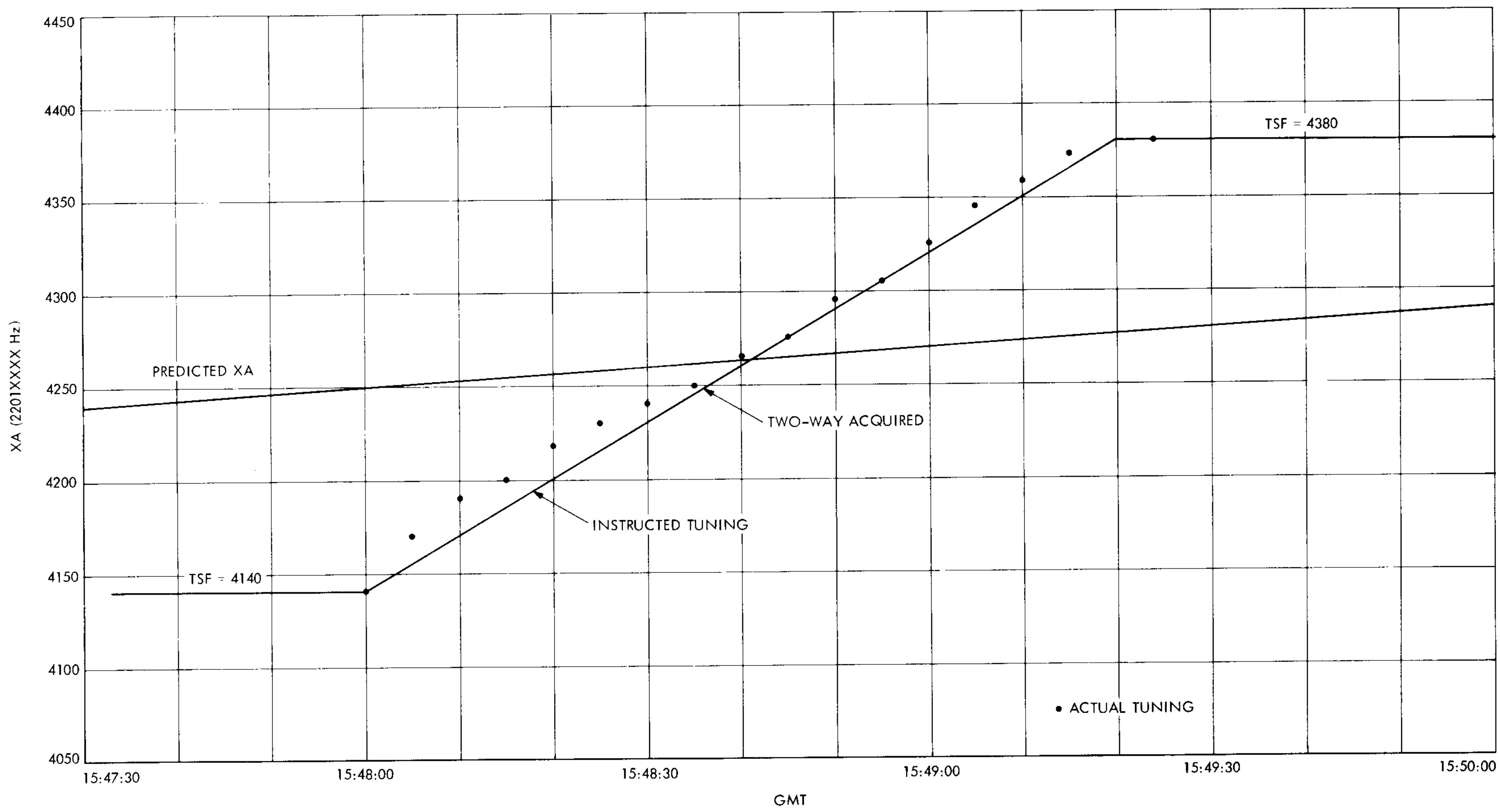

Fig. 6. Comparison of actual versus instructed tuning at DSS 12 Voyager 2 launch

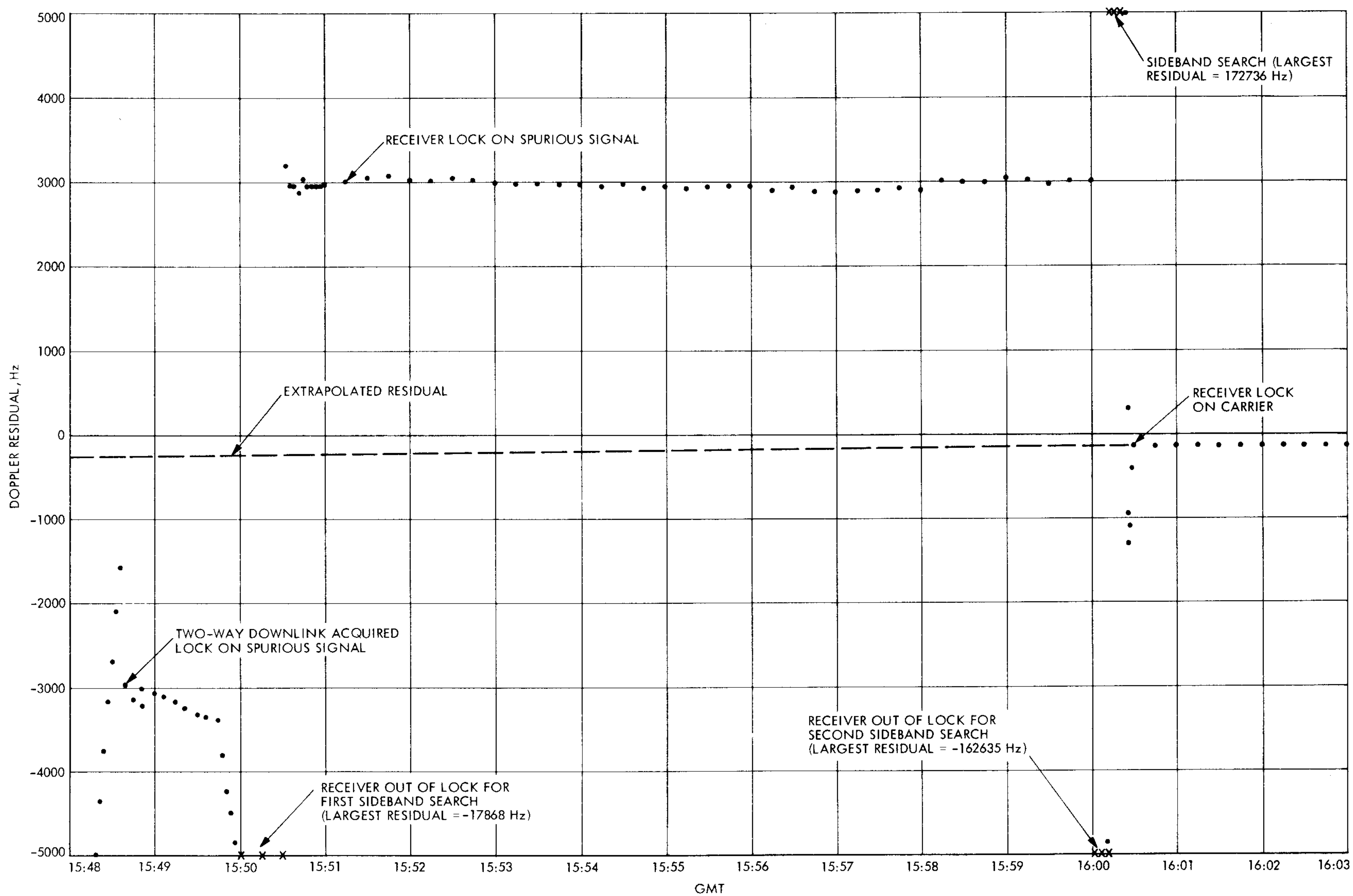

Fig. 7. Two-way doppler residuals at DSS 12, Voyager 2 launch