2. MISSION OPERATIONS TIME-LINE

This chapter provides a summary of activities and conditions that influenced the quantity and quality of the data return, and shows them in the form of a mission operations time-line. Due to its orbital problems, the mission operated under far from ideal conditions, and was subject to excessive radiation which ultimately destroyed vital parts of the electronic hardware and brought the mission to an end. In order to overcome the worst of these conditions and to recover the mission in the best possible way, there was intense collaboration and exchange of calibration and other results between the data reduction consortia and the European Space Operations Centre in Darmstadt, Germany, coordinated by the European Space Research and Technology Centre in Noordwijk, The Netherlands. Most topics described in this chapter are dealt with more extensively in Volume 2 and various chapters of the current volume, most notably Chapter 8.

2.1. Introduction

The data quality and data return of the Hipparcos mission were affected by many different factors. Some led to improvements in the quantity and the quality of the data, such as the inclusion of additional ground stations and improved instrument calibrations; some were routine, such as refocusing, and gyro de-storage; while others were unwelcome side effects of the orbit Hipparcos was forced to use, such as large background variations, gyro failures, and interruptions of the real-time attitude determination near perigee. This chapter provides a summary of those events and their place on the time-line of the mission, as a general reference point for the many calibration results presented in this volume. In order to facilitate such comparisons, all figures in the current volume showing calibrated quantities over the length of the mission, are shown on the same horizontal scale as the summary figures in this chapter, such as the overall summary presented in Figure 2.1. The origin of the time scale is 1989 Jan 0.0 = JD 2 447 526.5.

2.2. Activities Leading to Improvements of the Data Quality

Over the entire mission length there was intensive collaboration between the reduction consortia, the input catalogue consortium, and the operations team at ESOC, aiming at improving the quality and quantity of the data return.

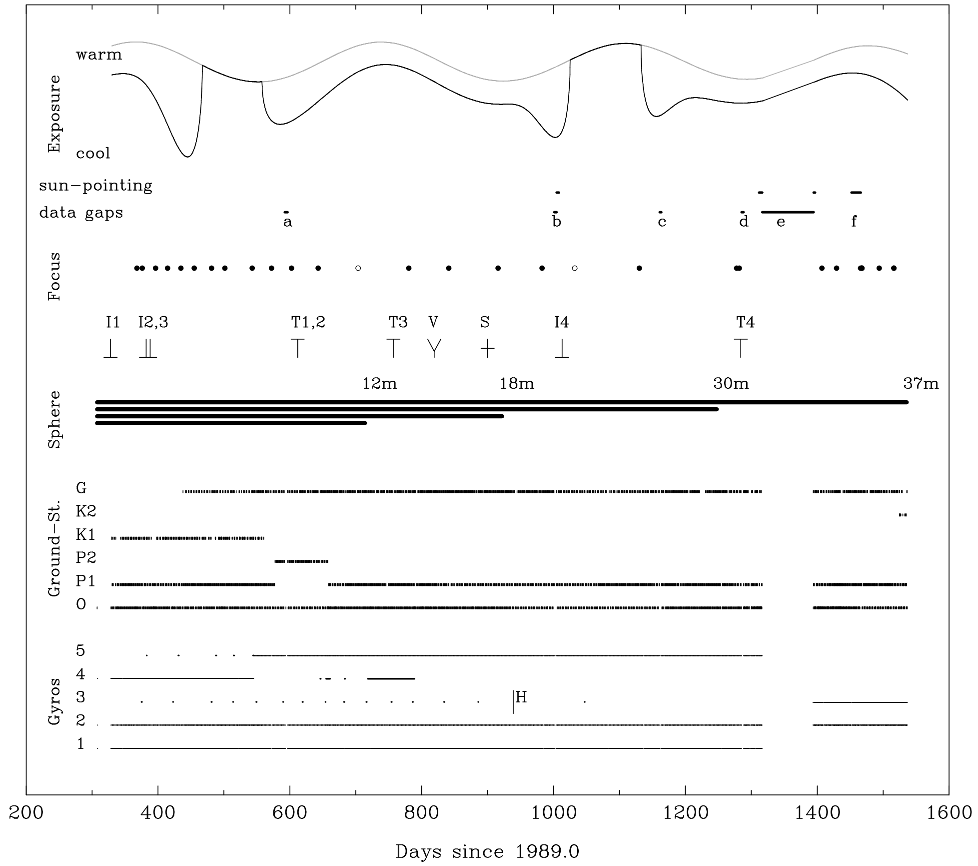

Figure 2.1. *Summary of various events that affected the Hipparcos mission. Table 2.1 lists chronologically events that had direct bearing on the data reductions, and explains some of the symbols in the figure. The ground stations used during the Hipparcos mission were: O: Odenwald; P1, P2: Perth (two receiver dishes); K1, K2: Kourou (two receiver dishes); G: Goldstone.*

Additional Ground Stations

The elliptical orbit Hipparcos occupied meant that contact with the satellite from the Odenwald ground station was only possible for limited amounts of time, leading to severe degradation of the mission. Additional ground stations were brought into operation at very short notice: first Perth, then Kourou, and later Goldstone. Of these, Odenwald and Perth were fully dedicated, while Kourou was also used during Ariane rocket launches and was no longer used when the Goldstone station became reliably operational. Goldstone also had other obligations, mainly towards the end of the mission, when the Kourou station was again used. Only the Kourou station could sometimes keep contact with the satellite during the perigee passage, but for almost all of the time there was no contact between satellite and ground station for 1 to 2 hours around perigee, and no observations were possible around that time. Two different receiver dishes were used in Perth and in Kourou (indicated in Figure 2.2 by P1, P2 and K1, K2 respectively). Figure 2.1 shows the use of the ground stations throughout the mission.

The final overall coverage is shown as part of Figure 2.4. Further details of the ground station commissioning can be found in Volume 2, Chapter 4. Chapter 8 in this volume presents the verification and calibration of the ground station delay times.

Table 2.1. Summary of the main events. Start and end times are given in days from 1989 Jan 0.

Start	End	Code	Event
328		I1	Correction of coil current calibration matrix
382		I2	Analogue mode anomaly detected
389		I3	Grid rotation calibration implemented
612		T1	Payload thermal control anomaly
632		T2	Change from mechanism drive electronics unit 1 to 2
592	596	a	Attitude lost, faulty attitude initialization
755		T3	Change from thermal control electronics unit 1 to 2
819		V	Spurious undervoltage
900		S	Gas tanks swapped
940		H	Gyro 3 heater failure
1001	1004	b	Uplink command error
1013		I4	Anomalous image dissector tube voltages
1161	1163	c	Data lost due to tape fault
1285		T4	Thermal control electronics 2 anomaly
1285	1288	d	Non-z-gyro patch introduced
1315	1396	e	Suspension of data acquisitions
1453	1466	f	Gyro 2 anomaly, sun-pointing for recovery

Instrument Calibration Upgrades

Various instrument calibrations were performed by ESOC and/or the data reduction consortia, some on a regular basis (the coil current calibration matrix, the main grid modulation coefficients), while others were produced as one-off inputs (grid rotation, basic angle, star mapper single-slit response functions). The latter type of calibrations all took place during the first few months of the mission, when the grid rotation and the proper pointing of the image dissector tube were established. By the end of January 1990 the instrument was known sufficiently well and data accumulation was no longer adversely affected by inadequate instrument descriptions. These calibrations are described in Chapter 5 of Volume 2.

Catalogue Updates

A major influence on the mission performance were the updates of the input catalogue. All updates were supplied by the input catalogue consortium, which acted on information supplied by the data reduction consortia as well as by ESOC. The first positional and photometric updates were obtained from the star mapper processing, later updates used preliminary sphere solution results. Large updates were confirmed by plate examinations before being implemented. These catalogue updates led to improved attitude convergence and pointing accuracy of the image dissector tube. Further details can be found in Volume 2, Chapter 8.

Hardware Calibrations

The calibration of the gyro orientations as supplied to ESOC by the NDAC consortium, provided a more accurate separation of gyro drift and therefore an improvement in the implementation of the gyro data in the real-time attitude determination. This implementation took place in June 1991 and can be recognized in Figure 13.4 in Volume 2 from the discontinuity in the drift values. Further details on the gyros can be found in Chapter 8, and in Volume 2, Chapters 13 to 15.

The calibration of the thruster firing performance as described in Chapter 8 was supplied to ESOC, but required no adjustment of operational parameters.

2.3. Routine Operational Phase

Refocusing

A wide range of data checks were carried out by ESOC on a routine basis and are described in Volume 2, Chapter 10. These data checks provided information on the performance of the main detector in terms of modulation coefficients and total signal intensity. From this information was derived the requirement to refocus the instrument, which happened at the start of the mission about every four weeks, later in the mission at longer intervals. Refocusing affected all data reductions relying on the amplitude or the phase of the modulated signal: great circle reductions (Chapter 9), ac-photometry (Chapter 14), double star processing (Chapter 13) and optical transfer function calibration (Chapter 5). For this reason, most (but not all) refocusing took place before or after the collection of useful data, i.e. close to perigee. The refocusing times are indicated in Figure 2.1.

Occultations

The lengths of Earth occultations near perigee was much longer than was foreseen for the nominal mission and led at some times to a temporary loss of attitude. In order to limit the impact of the occultations, ESOC experimented with decreasing the time-window during which the shutters were closed. As a result, there was less attitude loss associated with occultations, but the price was an exponential increase in the background for the star mapper and the image dissector tube detectors shortly before closing the shutters. This was difficult to accommodate in the routine data reductions, and was dealt with afterwards for the main mission photometric data (see Chapter 14).

Background Levels

The unforeseen orbit of Hipparcos, and the coincidence of the mission with a period of high solar activity, led to large variations in the background signal of primarily the star mapper detectors, as shown in Figure 2.2. The main contributor to the variations were the high energy electrons in the van Allen belts, which were encountered at least 4 times a day. These background levels influenced badly the performance of the real-time attitude determination, as it made the detection of a large number of fainter reference star transits in the star mappers impossible, thus reducing the number of available reference points. Figure 2.2 shows the background as the equivalent of stellar magnitude, indicating that at times near perigee even most of the brightest stars were undetectable.

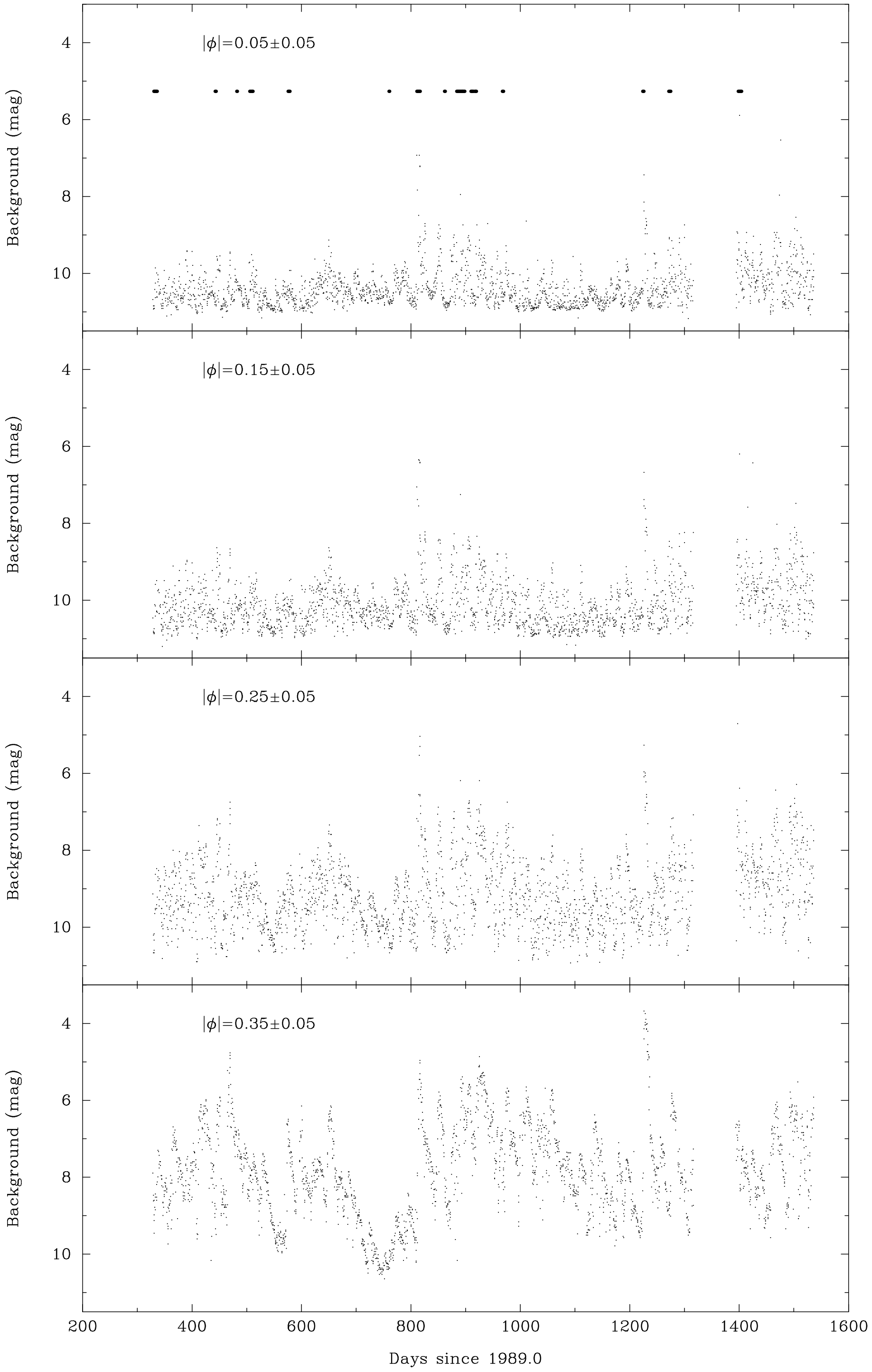

Figure 2.2. *Star mapper background levels in the* V_T *channel at different orbital phases over the mission. The orbital phases were measured from apogee. The top graph also shows events of high solar activity (just below the level of 5 mag).*

Thruster Firings

The cold-gas for the thruster firings was supplied from one of two gas-tanks. The pressure in those tanks was monitored, and in mid-June 1992 (day 900) the first tank was almost empty and swapped for the second tank (see Section 8.4 and Figure 8.9).

The thruster firing strategy was changed twice during the mission, using the experience obtained during the early parts of the mission. The first change involved a decrease in the minimum firing length from 4/75 s to 2/75 s. This took place around day 570. The second change affected only the firings around the z-axis: these firings were limited to those cases where the requirement for a firing translated into a firing length of at least 8/75 s. This took place around day 760. The main effect of these changes was a decrease in the amount of attitude disturbance, due to a decrease in the number and length of the thruster firings.

Ground Station Coverage Patterns

The orbital period of the satellite was intentionally close to 4/9 days, which led to repetitions in ground station coverage. This was most clearly so by the end of 1992 (around day 1050), when small changes in the orbital period meant almost exact repeats of ground station coverage patterns over a period of several weeks (see also Section 8.1 and Figure 8.2). This repeating pattern led to the use of the 4-day period in the examination of the data return statistics, as shown in Figure 2.4. Neighbouring periods of 4 days were little affected by the variations in coverage patterns that existed from one orbit to the next.

Gyro De-storage

Hipparcos was equipped with 5 gyros, of which three were needed for its nominal operations, the remaining two being redundant. In order to ensure that the redundant gyros were still in good working order they were subjected to a de-storage procedure once every 4 weeks. This procedure consisted of a 1-minute long spin-up to nominal spin frequency, followed by a period of approximately 2 hours of normal operations, followed by a 1-minute spin-down back to its storage configuration. As a result of those actions, the satellite was subjected to additional torques, most noticeably during the spin-up and spin-down phases. Such (short) stretches of data were lost (see also Chapter 7 and Chapter 8).

De-storage for redundant gyro 3 was stopped when it was found out that its heater had broken down.

Micrometeorites

External hits of the satellite, possibly by micrometeoroids, were recognized in the gyro readout records as discontinuities not associated with thruster firings. Two fairly substantial hits and 10 to 15 smaller ones were recorded. The larger hits were roughly equivalent to thruster firings lasting 0.2 s, causing a change in rotation rate of the order of a few arcsec s^{-1}, the smaller ones were mostly about ten times smaller.

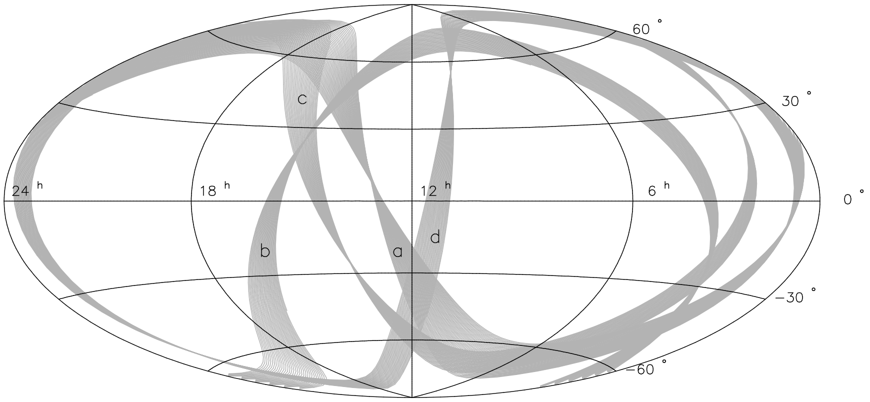

Figure 2.3. *Sky coverage of the nominal scanning law for times affected by data loss or sun-pointing recovery. See Table 2.1 for the meaning of labels a, b, c, d.*

2.4. Events and Failures Leading to Loss or Degradation of Data

The main events that led to some degradation of the Hipparcos data were generally associated with failures: from the orbital problems due to the apogee boost motor failure, through various thermal control electronics anomalies to the final failure of the gyro electronics and the on-board computer. Table 2.1 lists chronologically the events that were most noticeable in the data reduction and calibration results, summarizing also some of the events mentioned in the previous two sections. Figure 2.1 shows these events along the mission time-line. Below follows a brief description of the consequence of some types of failures and anomalies.

Data Gaps and Sun-pointing

Gaps in the scanning of the sky were caused by uplink command errors and by hardware failures. The main effect of such data gaps was in the final results: as the satellite described a pre-defined scanning law, every data gap would cause a gap in the sky coverage, meaning that some stars along a ‘strip’ of sky, had missed their chance of being observed. Such events can sometimes be recognized from sky-maps showing the total number of observations per object. The astrometric and photometric data of the stars involved suffered an inevitable deterioration, and this was most serious for objects near to the ecliptic plane, for which the density of observations was already lower than in other parts of the sky, and for objects affected by two or more of these events. The distribution of sky coverage affected by data-gaps before the interruption of observations on day 1315 is shown in Figure 2.2. The effect of data gaps can be seen in Figure 14.16 for the photometric data.

Sun-pointing had three effects. It caused a disruption of the scanning law, with the same effects as for data gaps; a narrow strip in a different part of the sky was very densely scanned instead; the changed exposure of the satellite to sunlight caused changes in temperature of the spacecraft, leading to problems with calibrations. Thus, especially in photometry, sun-pointing data were often unreliable, while consisting on the other hand of often longer stretches of observations. Data obtained immediately following a sun-pointing mode period was subject to rapid changes in spacecraft temperature. From the astrometric point of view, the sun-pointing data only contributed to the determination of position and proper motion in ecliptic latitude, the displacements due to parallax and the longitude components being perpendicular to the scan direction and thus not measurable on the main grid.

Thermal Anomalies

Thermal anomalies were associated with heater failures, and caused a drift in the temperature of the payload on a few occasions. Such thermal anomalies had therefore the same effect as refocusing, most noticeably the thermal control electronics failure indicated by T3 in Table 2.1 and Figure 2.1. This failure caused a run-away effect for the focus, and the recovery, through employing a redundant heater, brought the focus abruptly back in line (see Figure 14.3, the discontinuity at day 755 associated with event T3). This was accommodated in the reductions by associating the time of recovery with a pseudo-refocusing event, so that calibrations relying on running solutions would implement an appropriate break at that position in time.

Gyro Failures

Gyro failures were first indicated by noise bursts, i.e. sudden increases in the noise on the gyro readings. This affected the attitude control possibilities, in particular around perigee when no ground-station contact and star mapper transits were available as an additional control. The actual failure was accompanied by spin-downs and haphazard torques working on the spacecraft, resulting in loss of control and recovery to sun-pointing. The failure of both z-axis gyros led to the need for operating the spacecraft on two gyros only, one of which (gyro 3) had a failed heater. The consequence of this was increased sensitivity in gyro drift to temperature fluctuations in the spacecraft, and the presence of low amplitude modulated noise on the readings (see Chapter 8 and Volume 2, Chapters 13 to 15).

2.5. Data Return

Many of the points mentioned in the previous sections contributed in a positive or negative way to the overall data return. Primarily, however, this was determined by ground station coverage, occultations, and the success rate of the real-time attitude determination convergence. The overall data return over the mission (in units of 4 days) is shown in Figure 2.4; it averaged just over 60 per cent.

Real-Time Attitude Determination Convergence

Successful data collection could only start after the real-time attitude determination loop had converged: when predicting oncoming transits of star mapper stars, it would find them at the expected time and place. After a perigee passage the attitude control would often be lost, and in need of ground-based assistance to converge again (see Volume 2). There were no clear patterns recognized in the time and effort it took to re-converge the

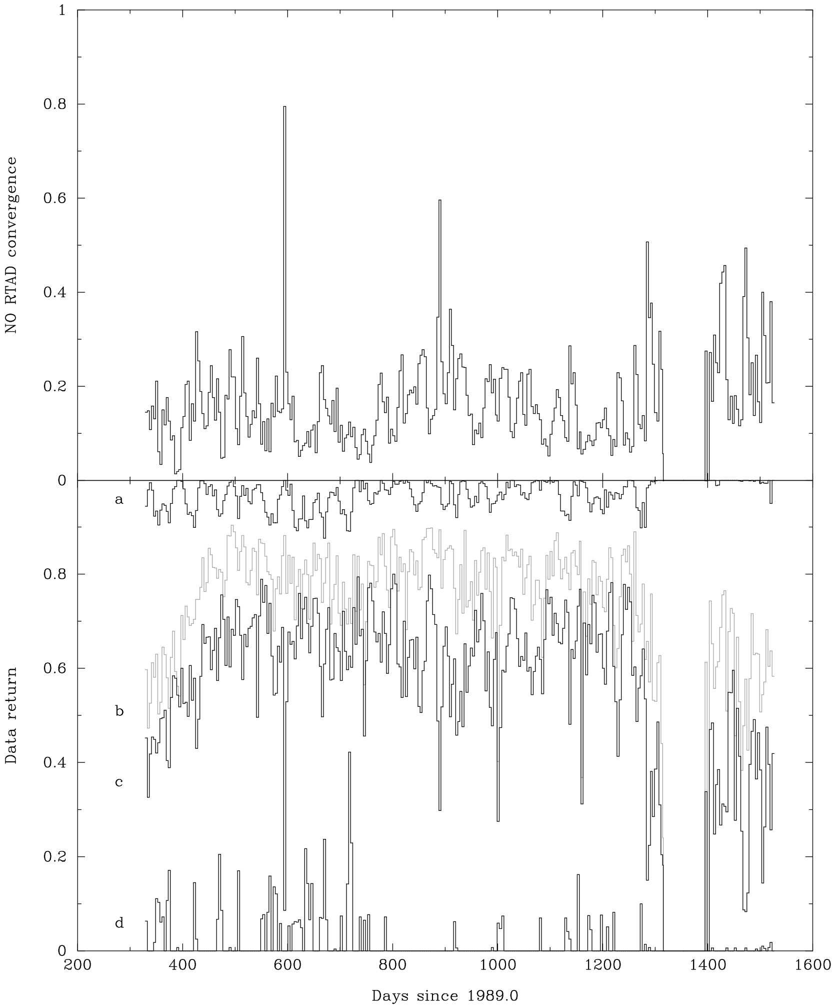

Figure 2.4. *The data return summary over intervals of 4 days (close to 9 orbits). The top graph shows the fraction of time lost due to 'no attitude convergence'. The bottom graph shows between the upper boundary and curve 'a' the fraction of time lost due to occultations during data coverage. Curve 'b' (dotted) shows the maximum possible data return (ground-station coverage minus occultations). Curve 'c' shows the actual data return. The difference between 'b' and 'c' is the same as the curve in the upper graph. Curve 'd' shows the fraction of data contained in data sets of less than 1200 frames, usually too short to be included in the final results. The difference between curves 'a' and 'b' shows the fraction of time lost due to 'no ground station coverage'.*

attitude (in other words, with how far the satellite had drifted away from its assumed attitude), no relations with perigee height were detected (low perigee caused drag and could have influenced the satellite pointing). There was, however, almost certainly a relation with high background level in the star mapper detectors near perigee, effectively extending the period without attitude control. Other influences were occultations very shortly before perigee, effectively increasing the time span without observations.

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