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OAO 2/Wisconsin Experiment Package (WEP) Photometer Users Guide

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OAO 2/Wisconsin Experiment Package (WEP) Photometer Users Guide

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November 1974

NOTE

To the recipient of this document. Page numbering may not show continuity throughout. This is intentional because of layout requirements.

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PREFACE

This users guide was written in large part at the National Space Science Data Center (NSSDC) based on information supplied by the principal investigator, Professor A. D. Code, and his co-workers at the University of Wisconsin. Several sections of the manual were written by them directly. While this manual is the most up-to-date available, it will be revised as new information becomes available. For this reason each page, table, and figure carries the month and year in which it was written. As new information becomes available and segments of this manual are rewritten, all persons who have requested copies of this manual from NSSDC will automatically be sent revisions. For this reason the manual is not bound but instead is punched for a standard three-hole binder.

The user is warned that all reduced data from the computer reduction program DROOP (data reduction of OAO photometry) have been produced with only minimal regard to whether the data were valid. The validity of the overall data must be checked by the user, and further corrections (e.g., filter degradation corrections, system dead-time corrections) must be applied. This guide has been written to enable the user to check the validity of the reduced data, to add additional corrections to the data, and, if necessary, to hand-reduce data independent of the DROOP software.

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1. INTRODUCTION

This users guide is intended to help astronomers use data from the Wisconsin Experiment Package (WEP) flown on board Orbiting Astronomical Observatory 2 (also called OAO 2 or OAO-A2 and given the international designation 68-110A). This observatory was the second in a series of four OAO spacecraft that were launched. The first failed shortly after launch due to power supply problems. The third satellite failed to attain orbit when a shroud failed to separate from the launch vehicle. The fourth OAO, given the name "Copernicus," was successfully launched and is still in operation.

OAO 2 was launched on December 7, 1968, and was operable until February 14, 1973. It carried two sets of experiments: the WEP, to be described in detail later, and a package called the Celescope Experiment that consisted of four independent telescopic Schwarzchild cameras (1200 to 2900 A). The Celescope Experiment was built and operated by the Smithsonian Astrophysical Observatory (SAO). A catalog of the objects observed with the Celescope is available from the National Space Science Data Center (NSSDC), Code 601.4, Goddard Space Flight Center, Greenbelt, Maryland, 20771, under experiment identification number 68-110A-01. Copies may be purchased from the Government Printing Office (Stock Number 4700-00260, price $4.85 domestic, including postage; $4.50 plus postage foreign).

The WEP consisted of three groups of instruments: a set of four stellar photoelectric photometers located behind 8-in. telescopes, a nebular photoelectric photometer located at the prime focus of a 16-in. telescope, and a set of two objective grating spectrometers. Each stellar photometer was situated behind a filter wheel that contained three filter passbands, a calibration slide (strontium90), and a dark slide. The 12 filters had effective wavelengths from 1330 to 4250 A, while the passbands ranged from 200 to 840 A (full-width half-maximum). The filters were arranged among the four instruments to provide redundant coverage so that the telescope responses could be cross-correlated. Two field stops were provided for the experiment, with angular diameters of 2 arc-min and 10 arc-min. Photons were detected by photomultipliers. These photomultipliers drove both pulse counters and DC amplifiers, thus providing redundant output. The analog (DC) channel of Stellar Photometer 4 was not functioning at launch and provided no useful data. The filters experienced some degradation in orbit, so corrections to be applied to the stellar photometer data are presented in Chapter 2.

The nebular photometer was located behind a six-position filter wheel providing passbands from about 2130 to 3330 A (effective wavelength), a calibration slide, and a dark slide. A pulse counter and a DC amplifier similar to those used with the stellar photometers were used with this photometer. About 2-1/2 months after launch, a failure left the calibration source permanently in place, and no further data resulted from this detector.

Spectrometer 1 covered the wavelength range from 1800 to 3800 A in 100 steps, with resolutions of 20 or 200 A (selectable). The slit width of 20 A corresponded to 2 arc-min projected on the sky, and the slit height corresponded to 8 arc-min.

Spectrometer 2 covered the wavelength range from 1050 to 2000 A in 100 steps, with resolutions of 10 or 100 A (selectable). The slit width of 10 A corresponded to 1 arc-min projected on the sky, and the slit height corresponded to 8 arc-min.

Three basic modes of operation were used: (1) Mode A, in which the four stellar photometers were operated together, (2) Mode B, in which the nebular photometer was operated, and (3) Mode C, in which one of the two spectrometers scanned (both could not scan simultaneously).

During any mode of operation, data were collected from all instruments. Because of alignment problems, however, the photometers and spectrometers did not view the same area of the sky. Special purpose modes were also available. Figures 1.1-1 and 1.1-2 show the areas of the celestial sphere observed by this experiment.

Aside from the failures of the nebular photometer and the analog channel of Stellar Photometer 4, and the degradation of the filters, most of the instruments operated normally from launch until spacecraft operations ceased. Due to its unreliable filter wheel positioning, Stellar Photometer 2 was left in a fixed position for the last third of its operating life. Intermittent malfunctions occurred in the digital channels of Stellar Photometer 1 and Spectrometer 1.

Descriptions of the experiment can be found in "Ultraviolet Photometry from the Orbiting Astronomical Observatory. I. Instrumentation and Operation," by A. D. Code, T. E. Houck, J. F. McNall, R. C. Bless, and C. F. Lillie, Astrophysical Journal, Vol. 161, pp. 377-388, August 1970, and "The Scientific Results from the Orbiting Astronomical Observatory (OAO 2)," NASA SP-310, from the National Technical Information Service, Springfield, Virginia 22151 (Library of Congress Card 600185, price $6.00).

This users guide is intended to enable astronomers to reduce the filter photometry data obtained by the WEP carried on the OAO 2 spacecraft. Only information related to the stellar photometers will be presented, since the nebular photometer failed after 2-1/2 months of operation, while the stellar photometers provided roughly 49 months of data. The spectrometer data will be covered later in a separate publication.

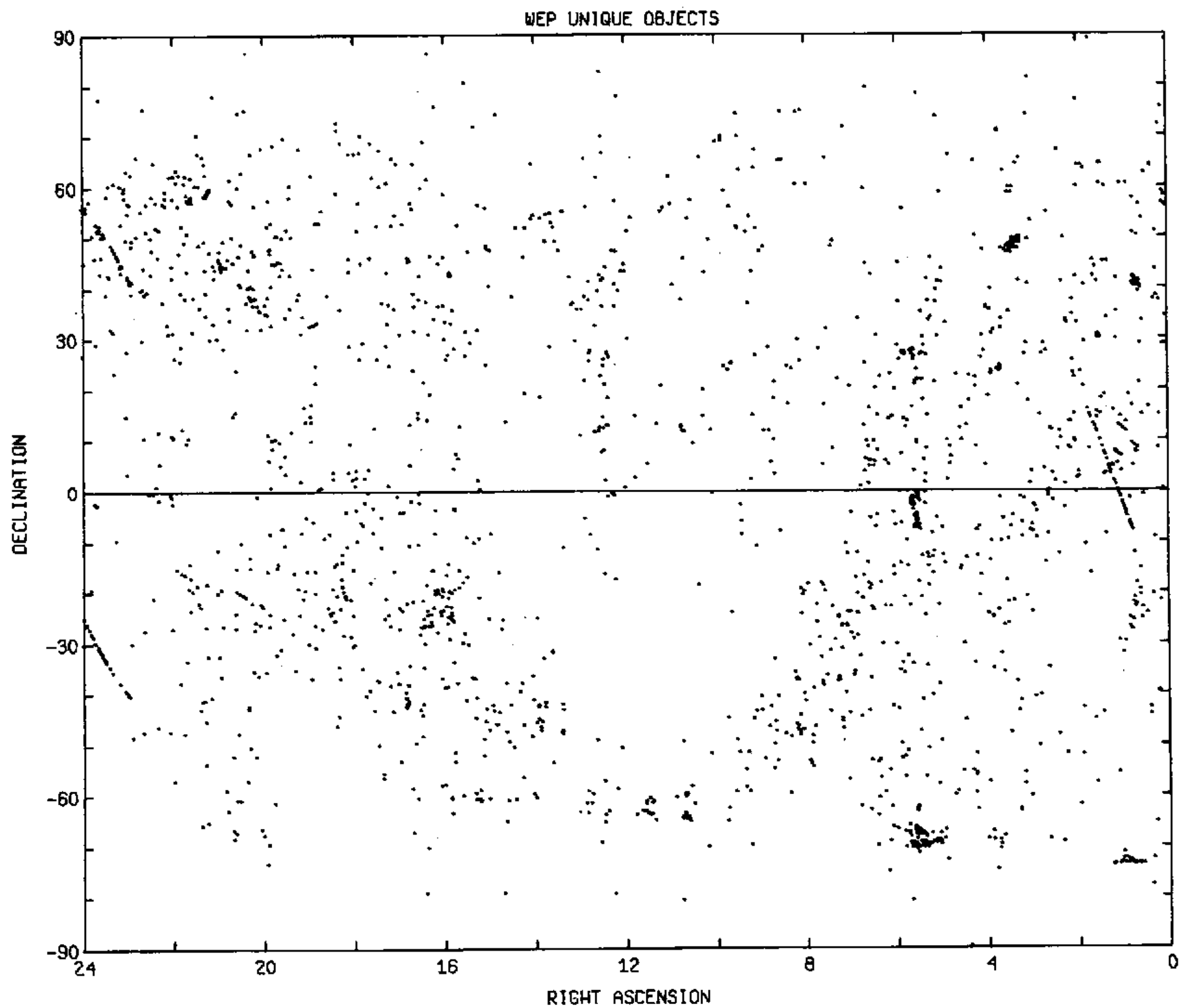

Figure 1.1-1. Objects Observed with the Wisconsin Experiment Package (WEP) on OAO 2

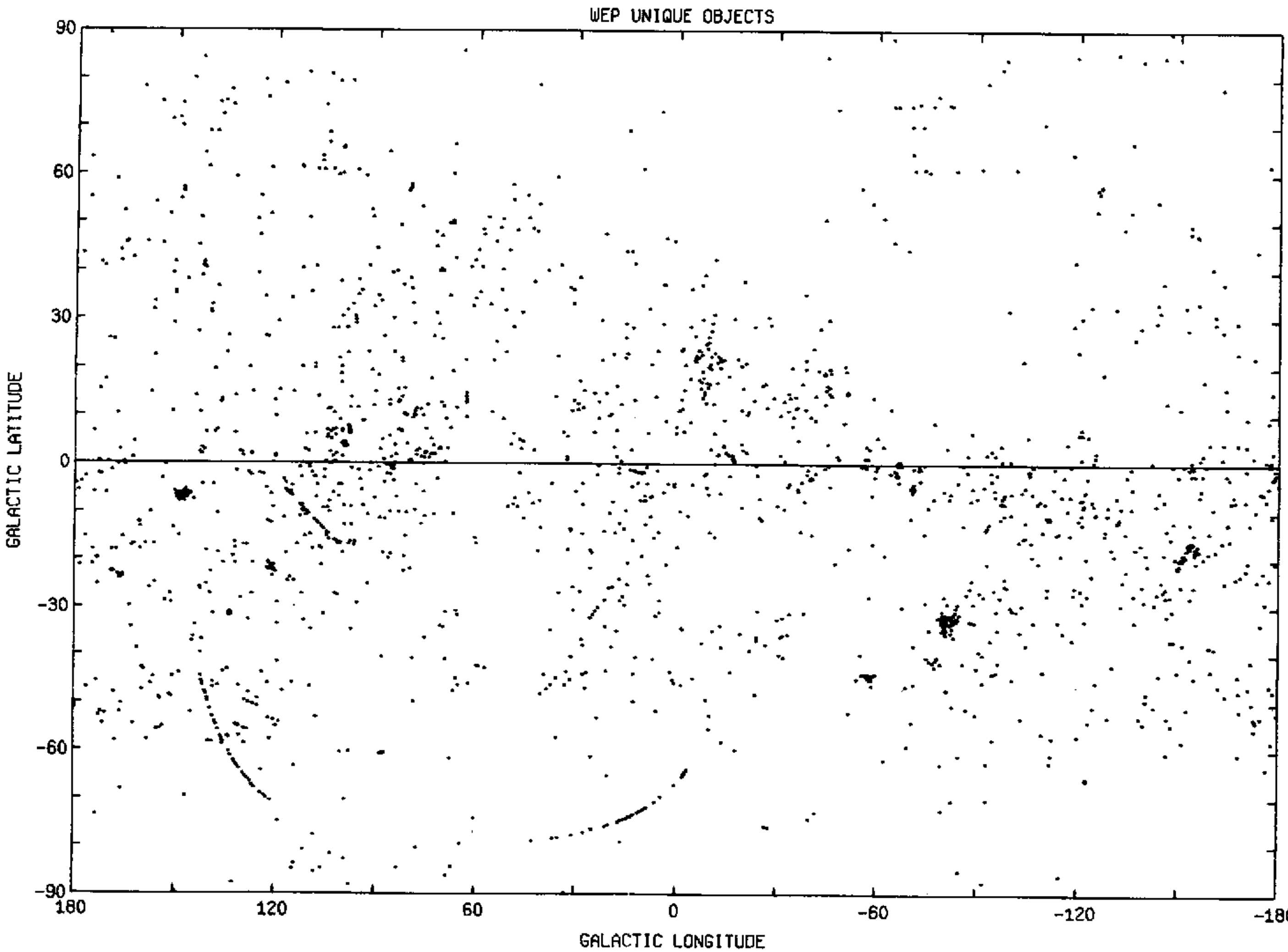

Figure 1.1-2. Objects Observed with the Wisconsin Experiment Package (WEP) on OAO 2

As with any instrument, the stellar photometers exhibited peculiarities which varied with changes in the environment or which varied secularly. Because the environment at an altitude of 480 miles imposed several observational difficulties, as did operational constraints set by the spacecraft as it aged, and because the instruments were pushed to the limits of their sensitivity upon occasion, great care must be taken in reducing OAO data. Properly reduced, however, much of it is fully comparable in quality with the best data from ground-based telescopes.

This guide is not the final word on reducing OAO data. Updates will be issued as more becomes understood about the idiosyncrasies of the system, and as time-dependent system changes become evident. Nevertheless, most of the filter photometry amenable to computer reduction can be understood by studying this guide. Before starting, however, the user is cautioned that he should read thoroughly the article by Code, et al., mentioned above. The volume on the scientific results from the Orbiting Astronomical Observatory (OAO 2) (NASA SP-310) also contains useful information.

1.1 DATA REDUCTION SUMMARY AND SIMPLE "DROOP" VERIFICATION

As any observer or experimentalist knows, even the best-planned measurement can be influenced by a great many factors. A satisfactorily complete data reduction scheme should take all such influences into account. However, it has not proven a practical possibility to incorporate into an automatic routine all the checks, tests, and methods one might employ in a hand reduction. Thus, the DROOP program has been designed as a compromise between simplicity in programming and thoroughness in number of observations reduced.

There are two purposes for including this section. The first is to summarize as generally and briefly as possible the procedures that may be followed to transform worthwhile raw data into usable reduced data. The second is to provide a guide to enable one to evaluate the validity of DROOP-reduced data and to correct errors or inaccuracies. All the procedures mentioned below are detailed in subsequent sections of this document. Most of the factors that can vitiate worthwhile data are also elaborated elsewhere. For the purposes of this section, it will be assumed that reasonable integration times have been used to observe stellar objects through appropriate filters. The techniques for reducing observations of extended or very faint objects, for example, are basically the same as for more intense bodies, but extra care must be taken at several stages for proper interpretation of the data.

The astronomer who planned the observations for a given interval of orbits was responsible for choosing the objects, the mode of operation (scanners or photometers), the integration times, and either the number of scanner steps or the filters. Generally, observations were timed to occur while the spacecraft was in the Earth's shadow to minimize problems with scattered light and photomultiplier dark counts. For photometry, once a chosen configuration of filter wheel positions among the four photometers was obtained, the associated integration times were held constant for six successive observations. Thus, the minimum block of data consists of a set of six numbers (raw digital counts) for each of the four instruments. Most of the commonly used observing sequences were comprised of from 8 to 11 such "frames." With three filters per photometer, this allowed time to gather object data for two or more different integration periods per filter and also to make calibration-source and dark-slide observations.

It is the goal of the reduction scheme to apply some known corrections and determine some others, so that one can compute valid individual frame data for each filter and combine these into an average for that orbit. These results can then be compared with other data, regardless of the date of observation. An important short-term correction, for example, is the dark count signal and its variation through spacecraft night. One of the known long-term effects is the weakening of the calibration source through radioactive decay.

Let the four choices of integration time (exposure) be denoted by E_i = 1/8, 1, 8, and 64 seconds for i = 1, 2, 3, and 4, respectively. For any frame and photometer, whether object, dark, or calibration data, let the six raw digital count results be:

$$\text{Raw Counts}_j(Ei) = n_j,\ j = 1,\ \dots\ ,6. \qquad (1.1\text{-}1)$$

Each number represents the state of an eight-bit counter at the end of an integration interval. If more than 256 counts have presented themselves at the input of a counter, then it will have reset to zero and continued accumulating counts. No record of overflows is kept by the experiment data collection hardware, but fairly reliable methods have been developed to detect such occurrences. These techniques are explained in Section 4.2. For now, let m_j be the number of overflows for the data in question. Hence, one can write:

$$\text{Total Counts}j(Ei) = n_j + 256m_j. \qquad (1.1\text{-}2)$$

For ST1 F3 (Stellar Photometer 1, Filter 3) and, more rarely, ST1 F1 and ST3 F2, the count rate for brighter stars can be high enough so that some dead time occurs in the counting electronics. Corrections for this effect can be found in Sections 2.2 and 4.3. For now, let the estimated number of missing counts be Δn_j. It is also known that the calibration sources in Photometers 3 and 4 are so intense that some spurious counts are recorded when the filter wheels are in dark or filter positions. A table of these bias counts is given in Section 2.1. One more correction that can be applied at this stage is to subtract one half-count, regardless of instrument or filter. Because of the continuously accumulating six-bit prescaler ahead of each counter, an extra output pulse will be recorded about half the time when the prescaler-to-counter circuit is made complete by the command to begin an integration. Including these last three items, one has:

$$\text{Total Corrected Counts}_j(Ei) = n_j + \Delta n_j + 256m_j - \text{bias} - \frac{1}{2}. \qquad (1.1\text{-}3)$$

For a hand reduction, it is desirable to average the six data points within a frame as early in the calculations as possible. Once the overflows have been determined, the only practical obstacle to immediately averaging the six values is determining whether or not the dark count variation is significant within the elapsed time of the frame. This determination can be made by comparing the dark current at the beginning of a frame (t_i) with the dark current at the end (i.e., at t_i + 6 x longest exposure time). Dark variations over the time interval of an entire observing sequence are common, particularly in the first and last minutes of spacecraft day/night transition. The time scale of fluctuations is such that for most observations, variations within a frame are significan only for the first few and last few frames of a sequence (near a light/dark transition) executed with an E4 integration time. It usually is sufficient, for all other frames, to interpolate a dark-counts versus time relation at the midpoint of that frame and subtract it from the average of the six data points. For most frames, then, the last two equations could be rewritten suppressing the index j, with the understanding that the results stand for the average of six data points.

If no dark variations within an E4 frame length are significant, then one might ask next whether it should be necessary to do a dark curve fit at all. In doing a hand reduction, one can note the relative sizes of the object counts, dark counts, and variations in dark counts. If the size of the fluctuations is small with respect to the expected accuracy of the object data, it is reasonable to take a simple average of individual dark frames and pay no further heed to the time of execution of any object data frames. There are numerous occasions, however, when this is not satisfactory and a plot of dark slide data versus observation time is required. In any case, inexperienced users of WEP photometry are encouraged to make a few such plots to acquire some familiarity with the magnitude and time behavior of the dark signal; this will be of benefit when evaluating the accuracy of DROOP-processed data. DROOP does not make any judgments about when to form a time-dependent dark curve fit but does its best to do so all the time. This situation, which leaves ample opportunities to go wrong, will be discussed below.

At this stage it can be considered that each frame has been reduced to a form of corrected E2 counts with some estimate of the dark signal subtracted. The frames of interest now are object data (called STAR - DK) and calibration data (CAL - DK). Individual frame results for each filter can now be compared and an overall average derived. One note of caution here is that if the photometry sequence includes, for example, three different integration periods, the shortest one may have so few counts that it should not be included in the final average.

The first correction for long-term system response variations is necessary because star data are normalized to the calibration source signal. The strontium^{90} calibration source decayed significantly during the operation of the observatory and must be corrected back to an equivalent intensity at the date of launch (see Section 3.1 or 4.0). Rather than do this on a frame-by-frame basis, DROOP averages all the CAL - DK results for an entire raw data tape (about 1/3 to 1/2 of a week's observations) and corrects these averages back to launch. The overall stability of the photometers is such that this method yields higher accuracy than individual calibration measurements. These quantities are listed at the beginning of each DROOP tape or printout and repeated on each observing sequence summary page. Even if DROOP has failed to reduce data properly for a particular star, the level of drudgery in any subsequent hand reduction is reduced a worthwhile amount by having the values of CAL - DK already available. Note that the individual frame results for CAL - DK do not include the decay correction.

Performing the normalization mentioned above gives the following quantity:

$$\frac{\text{STAR - DK}}{\text{CAL - DK}} \qquad (1.1\text{-}4)$$

Exercising no judgment as to when one should exclude a low-count frame, disregarding any possible counter dead-time correction, and determining the dark values similarly, the above quantity should be identical to that given by DROOP next to the label DIGITAL. Note that the STAR value includes both the object desired and a contribution due to the sky background (SKY). This background has components due to geocoronal emission, celestial sources in the field of view, zodiacal light, sunlight scattered by the near-Earth orbit, and occasionally moonlight scattered into the telescopes. Thus, compensating SKY measurements should be made "near" the object of interest in both space and time. In practice, SKY observations are made far enough from the original STAR pointing so that any extraneous object in the original field of view is probably not included in the SKY data. As a consequence, one should examine the area a few arc-minutes around any object of interest for possible contaminating stars (see "Ultraviolet Photometry from the Orbiting Astronomical Observatory. IV. Photometry of Late-Type Stars," L. R. Doherty, AP. J. 178, 1972, p. 727 for a discussion of this problem). If field stars are no problem and a satisfactory SKY observation is available, then one can define a quantity $R'(\lambda)$ for each filter of effective wavelength λ as follows:

$$R'(\lambda) = \frac{\text{STAR}(\lambda) - \text{DK}}{\text{CAL - DK}} - \frac{\text{SKY}(\lambda) - \text{DK}}{\text{CAL - DK}} \qquad (1.1\text{-}5)$$

The orbit of observation must still be associated with these photometric quantities because of the filter degradation problem. This behavior is typified by a steady decrease in filter transparency in the first several thousand orbits. For some filters this is followed by a period of more rapid decline, then by a partial recovery with one or two episodes of very short-term variability. The details are presented in Section 2.1. If the effect at the epoch of observations is adequately described by a loss of sensitivity of $\Delta m(t)$ magnitudes, then a digital quantity $R(\lambda)$, which is as close to being orbit-independent as is currently possible, may be defined as follows:

$$-2.5 \log R(\lambda) = -2.5 \log R'(\lambda) - \Delta m(t). \qquad (1.1\text{-}6)$$

These $R(\lambda)$'s and the calibrated OAO magnitude system (see Section 4.7) are the foundation and framework for all further studies based on the WEP photometry. The accuracy of the photometry can range from bad to excellent. Data for many stars with wide ranges of brightness and color excess and collected over the entire lifetime of the spacecraft can yield, for example, ultraviolet color-color plots with least-square errors of one-tenth or two-tenths of a magnitude (rarely more). On the other hand, observations of a single object over a few days or weeks is often repeatable to within 0.01 magnitude or better.

The operations performed by DROOP may be generally outlined as follows. The results of some auxiliary programs are required as input to the routine (see Section 3.1 for a description). The ones most relevant to this discussion are the relations between the analog voltage and digital counts at various exposures for each instrument (used in estimating the counter overflows) and the relations between the dark counts on three of the instruments in terms of a fourth (used in estimating the dark signal for a photometer with poor or incomplete dark data).

A raw data tape is first examined in terms of blocks of time defined by observations conducted in and about periods of spacecraft night. For each episode CAL and DK data are reduced, a dark curve fit is derived, and the fit is used to compile a set of CAL - DK values. When this first pass through the tape is completed, the means of the net CAL results are corrected for the source decay since launch, and the four CAL - DK quantities are available for the second pass through the tape. In this pass, filter data for individual target pointings are reduced using the appropriate dark curve fit. For each target, filter data are averaged (weighted inversely by the estimated error) and presented in summary form. As qualified above, this tabulated digital result is essentially that given by Equation (1.1-4). Also listed in the summary is OAO-MAG, which is the DIGITAL result converted to magnitudes, with the preliminary relative calibration constants added.

In relation to the reduction scheme that led to Equation (1.1-6), it should be emphasized that DROOP does:

1) <u>not</u> check large signals for possible counter dead-time corrections,

2) <u>not</u> distinguish between STAR and SKY observations and, hence, does not perform any sky background subtractions,

3) <u>not</u> apply filter degradation corrections,

4) perform a dark curve fit (subject to the vagaries of poor or incomplete data),

5) estimate overflows (by an approximate procedure that can fail, especially for Stellar Photometers 3 and 4),

6) average filter data (without deleting frames of especially low quality or those of short integration time), and

7) exclude object data collected while the spacecraft was in the predicted regions of sunlight or the South Atlantic Geomagnetic Anomaly.

Therefore, the user of DROOP-processed photometry must surely carry out several operations to derive data that can be compared to other results on the basis of Equation (1.1-6), i.e., at least the filter degradation and SKY background corrections and the final calibration constants should be dealt with. A user may also be forced to mend flaws in the DROOP results, most likely in the areas of overflows and dark counts.

The rest of this section is devoted to giving a few hints on how to verify the results of DROOP-reduced photometry in a fairly rapid (but not foolproof) manner. A familiarity with the DROOP output format is necessary to verify any results; this format is described in detail in Chapter 3.

The first item that might be checked when faced with the task of evaluating an observation is whether all useful frames are included and none excluded. As implied by item seven above, the time in daylight is computed from a knowledge of the orbital parameters and the sizes and positions of the Sun and Earth. Usually only the first and last frames of an observing sequence are liable to be dropped due to sunny conditions. Dark data taken in sunlight are generally accepted if such a frame is not immediately followed by another dark frame in night time. This procedure is followed to achieve the greatest possible baseline on which to establish the dark signal. If the frame contains object data and has been rejected by DROOP, one may still wish to include it. If the six raw digital count totals are reasonably constant throughout the frame and consistent with other results for the same filter, they can probably be safely averaged with other data after dark current is subtracted. Data with inconsistently high signals and perhaps with strong drift have likely been contaminated by sunny conditions. They cannot be safely incorporated into the rest of the observations unless there is an adequate estimate of the dark count variations. This may be possible, but risky, if there are dark data in the preceding frame (see the discussion below on the handling of dark data). It is somewhat easier to exclude undesirable frames since one can simply re-average the acceptable frame results and ignore the biased DIGITAL average listed on the summary page. One should be sure, however, that a frame rejected as undesirable is also unfixable. If the result from a frame is inconsistent with others because of very few counts or because of a large drift in signal level, then one should not hesitate to throw it out. But if it appears to be bad due to an incorrect estimate of the overflows, then it is preferable to repair the damage and re-average the complete data set.

The region of the South Atlantic Geomagnetic Anomaly is not only much harder to define, but its effects can also be far more devastating. Frame data that have been flagged as occurring in the South Atlantic Anomaly are best treated with extreme suspicion, if not completely ignored. They are not reduced by DROOP but a hand reduction of such data for an object of interest might provide an instructive comparison with another observation taken under more favorable conditions. Occasionally, data affected by the South Atlantic Geomagnetic Anomaly are not flagged. This occurs because the DROOP program identifies the Anomaly as a geographic region (and therefore flags measurements made in the predicted region of the South Atlantic Geomagnetic Anomaly) and not from geophysical particle measurements. Such data are likely to have a sharp peak of dark noise during the middle of spacecraft night. Such observations are difficult to detect, but can be recognized sometimes by a strong drift within a frame.

The overall behavior of the dark signal is recounted below. In sunlight the count rate is at some relatively high level. As the spacecraft enters the Earth's shadow, the dark signal drops rapidly, in perhaps five minutes or less, to a fairly steady level. Upon re-entering the sunlight, the dark level once more climbs upward. The amplitude of this variation is much smaller in ST3 relative to ST1 or ST2 and is almost nonexistent for ST4. Thus, the quality of the fit of dark counts versus time derived by DROOP depends largely on the placement and integration time of dark frames in the observing sequence. In many cases, the predicted occurrence of a day/night transition is not reflected in a downward drift in the dark counts. This is the justification for the possible use mentioned above of object data not preceded by dark data.

If each photometer's activity begins and ends with a dark frame and hopefully with another one somewhere in between, there is a good chance the derived fits are entirely adequate. This method is noted on the dark-curve-fit page as an INDIVIDUAL FIT. A rapid check of the fit can be made by comparing the digital result for each dark frame with the associated least-squares-derived value. The former is listed as any other frame result under the column headed (DATA - DK)/(CAL - DK), although for dark data the quantity DK/(CAL - DK) is actually given. To its right, under the column headed DK/(CAL - DK), is the dark value interpolated for the midpoint of the frame. This frame-versus-fit comparison should be the first calculation performed in checking on the handling of dark data by DROOP.

If the observations lack the very desirable first-frame and last-frame coverage, then the available dark information from Photometers 1, 2, and 3 are transformed to a common basis (see Sections 4 and 4.5), and a joint dark curve fit is derived. This relation is then transformed back to the individual photometer in question and used for the dark curve fit. This procedure is labeled a COLLECTIVE FIT. It cannot be predicted whether it is better to use such a collective fit or simply to extrapolate to other frames from a photometer's incomplete dark data. Again, comparing specific frame results with the fit-derived value can be the deciding factor.

In cases where the dark signal is very important to an accurate reduction, another method can be helpful. By examining dark data from neighboring observing sequences, one can sometimes detect systematic trends in the dark signal from one sequence to the next. This procedure can aid in establishing the dark behavior for the observation of interest but may not be worth the effort for fairly bright stars.

Table 1.1-1 lists a representative range of dark counts at E2 for the four instruments. Values of SKY are also given for each filter based on data corrected for filter degradation. It can be noted that the dark count rate is not only a function of the thermal conditions in the spacecraft but also depends on previous passages through the South Atlantic Geomagnetic Anomaly. The bias counts are discussed in Section 2.1.

Table 1.1-1

Typical Ranges for DARK, SKY, and Bias Counts

Photometer	Filter	Sky (Counts at E2)	Bias Counts (at E4)
ST1	F1 3320 A	5-20	0
	F2 DARK	5-35(DARK)	0
	F3 4250 A	40-160	0
	F4 2990 A	2-16	0
	F5 CAL.	---	---
ST2	F1 2040 A	0.5-3	0
	F2 2950 A	2-8	0
	F3 DARK	1-3(DARK)	0
	F4 CAL.	---	---
	F5 2380 A	1-5	0

Table 1.1-1 (continued)

Photometer	Filter	Sky (Counts at E2)	Bias Counts (at E4)
ST3	F1 1910 A	0.2-1.5	0.5
	F2 2460 A	0.5-5	5.3
	F3 CAL.	---	---
	F4 DARK	0.3-1.0 (DARK)	6.8
	F5 1680 A	0.1-10	34.8
ST4	F1 1550 A	0.1-1.0	10.4
	F2 CAL.	---	---
	F3 1430 A	0.3-2.0	10.8
	F4 1330 A	2-8	2.0
	F5 DARK	0.2-0.5 (DARK)	1.0

The easiest place for DROOP to make a significant error is in computing the number of digital counter overflows. This has proven to be the most perverse problem to incorporate into an automatic routine. The technique for estimating the overflows is based on the correlation between simultaneously obtained analog and digital results. An initializing program, whose results are input to DROOP, derives a slope (volts per overflow) and intercept (voltage offset) for each data tape. These results are used to predict any digital overflows for each observation. Inspection of typical values shows that ST1 and ST2 will register about 1/2 or 1 analog volt at E1 before the digital counter overflows. This rate is such that DROOP can reliably predict the number of overflows, except for stars bright enough to saturate the analog channel at E1. In those cases, however, the results are also likely to be highly affected by the counter dead-time problem.

The difficulties increase for ST3 because its counter overflows approximately eight times as fast as that of ST1, and perhaps 40 times more rapidly than that of ST2 for the same voltage. Its lower sensitivity provides some relief, but bright, early-type stars observed at inappropriately long exposures still can spin the counter far more times than DROOP can accurately compute. The photometer with the shortest wavelength, ST4, has no analog data channel at all. DROOP tries to estimate ST4 results from ST3, based on numerous hand-reduced data, and supplies whatever number of overflows it deems necessary to provide consistency. Fortunately, ST4 has a fairly slow overflow rate, so although it may contain its share of errors, it is not as unreliable as ST3.

Most cases of inconsistent overflow totals between frames can be rectified by hand in a straightforward manner after some familiarity with the reduction procedures is gained. A detailed explanation of the methods for estimating the digital overflows is given in Section 4.2.

2. INSTRUMENTATION AND PERFORMANCE

The four 8-in. photoelectric filter photometers (Stellar Photometers 1, 2, 3, and 4) provided a versatile system that incorporated considerable redundancy and yielded a better shaping of the spectral bandpasses than could be achieved with a single detector and optical system (Code, et al., 1970). The spectral bandpass of each stellar photometer overlapped with that of one other stellar photometer to permit internal checking of calibration and to minimize the loss of ultraviolet coverage should one photometer fail. Nevertheless, each instrument was an independent system incorporating its own electronics. Each could be individually programmed.

The optical system that was used is illustrated in Figure 2-1. Each 8-in. off-axis paraboloid had a focal length of 81 cm and a collecting area of 325 sq cm. Two field stops were available, with angular diameters of 2 arc-min and 10 arc-min, respectively. Each telescope could be recollimated on command over a field-of-view of 20 arc-min to align all four instruments along the same optical axis.

Each stellar photometer system included a photomultiplier and a filter wheel. Each filter wheel included three filters, a calibration position, and a dark position. The filter wheel/photomultiplier combinations are discussed in Section 2.1. As the systems aged, some changes became apparent in the transmissions of individual filters, and some filters showed evidence of red light leaks. The degradations of the filters, as well as the calibration system, are also discussed in Section 2.1.

The electronics package contained in each stellar photometer system is discussed in Section 2.2. Included is a discussion of both the analog and the digital outputs.

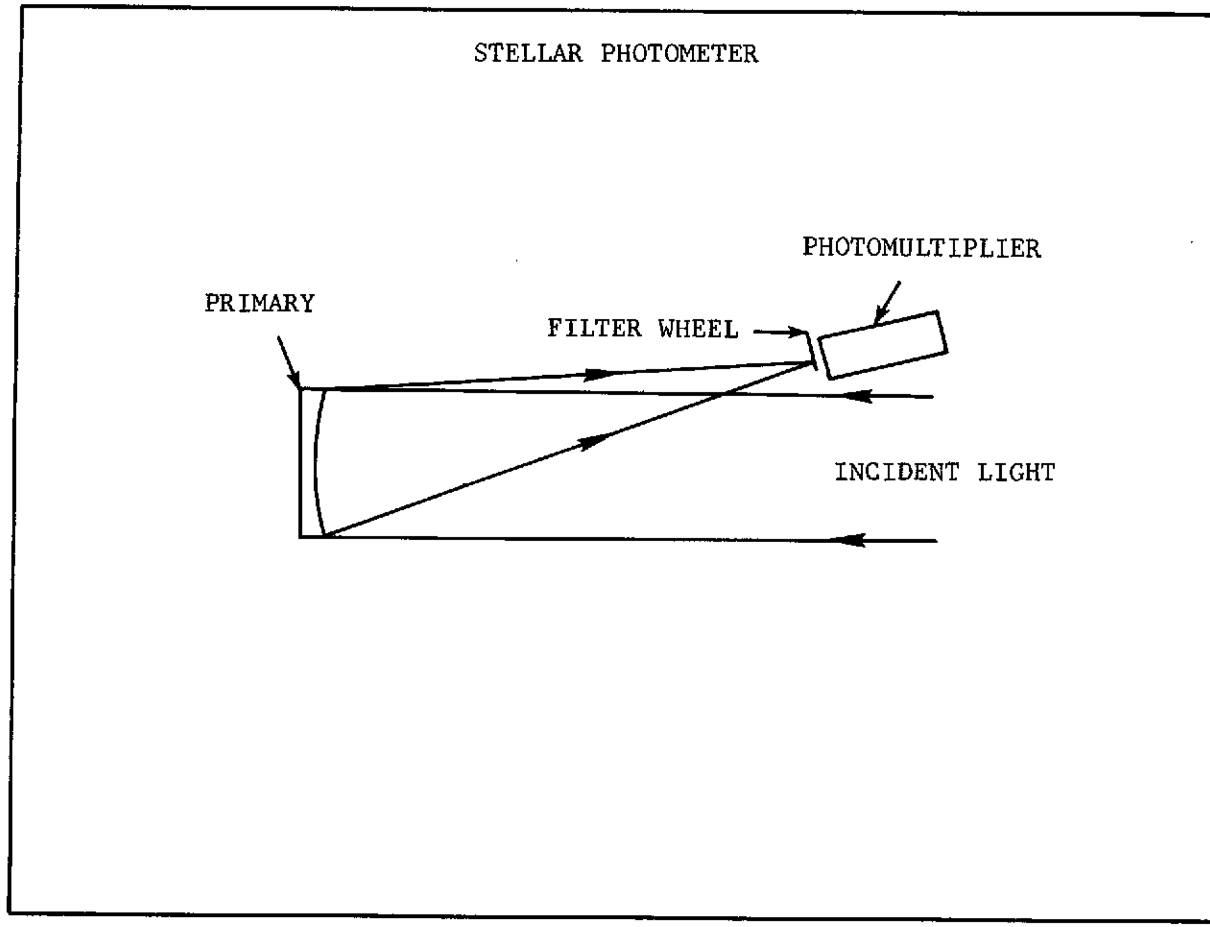

Figure 2-1. Optical System for Stellar Photometers

2.1 FILTER/PHOTOMULTIPLIER CHARACTERISTICS AND PERFORMANCE

Each stellar photometer system contained a five-position filter wheel that included three filters, a calibration source, and a dark position. Stellar Photometers 1 and 2 used EMI 6256B photomultipliers (cesium antimonide photocathodes), Stellar Photometer 3 used an ASCOP 541F photomultiplier (cesium telluride photocathode with a cleaved lithium fluoride window), and Stellar Photometer 4 used an ASCOP 541G photomultiplier (cesium iodide photocathode).

The filters were made up of combinations of glass blanks (e.g., UG11, BG12, or GG12), and interference filters (I.F.) formed by deposition on suprasil (fused quartz, F.Q.), calcium fluoride (CaF_2), or lithium fluoride (LiF_2).

A summary of individual filter and photomultiplier characteristics immediately follows the introductory pages to this section. The comments therein summarize the known idiosyncrasies of the filters and photomultipliers.

The preflight relative filter transmissions are presented, after the performance summary, in Figures 2.1-1 through 2.1-4 and Tables 2.1-1 through 2.1-4. All calculations were made using preflight calibrations and assuming no pinholes or red leaks. It should be noted that all calibration data were corrected for the decay of the strontium^{90} calibration source and normalized to the launch date. Tables listing relative filter transmissions data and associated figures plotting the data appear on facing pages.

Table 2.1-5 lists the filters for each stellar photometer along with the effective wavelength for a flat energy spectrum per unit wavelength interval and wavelength limits at half-maximum sensitivity.

Although many components of the WEP performed reliably for over 4 years in orbit, all of the photometer filters showed changes in transparency as a function of time. Provisional histories of the behavior of each filter are therefore presented in Figures 2.1-5 through 2.1-16. These figures show corrections to be applied to the data. These corrections are in the form

$$M(\text{corrected}) = M(\text{observed during orbit } t) - \Delta M(t). \qquad (2.1\text{-}1)$$

The corrections were determined from measurements of stars observed two or more times during the operating life of OAO 2, although not all stars observed at least twice were included in the figures. The observations were reduced by hand and converted into an arbitrary magnitude system by using the formula

$$\frac{(\mathrm{STAR} - \mathrm{DK}) - (\mathrm{SKY} - \mathrm{DK})}{(\mathrm{CAL} - \mathrm{DK}) \times e^{(5.27 \times 10^{-6} \times \mathrm{orbit})}} \qquad (2.1\text{-}2)$$

Measurements of the different stars were then shifted up or down until a smooth curve was determined. No observations made before Orbit 500 were included in the calculations since their inclusion would increase the scatter substantially. All curves were extrapolated so that at Orbit 0 the curve passed through 0.0 magnitude correction. The stars used to determine the curves for Stellar Photometers 1, 2, and 3 were selected so that saturation and the uncertainty of overflow would cause a minimum of problems. The degradation curves for spectral types B9.5-A1 in Figure 2.1-14 and for spectral types B8.5-B9.5, A0-A1, and A2 in Figure 2.1-15 were derived from the curves discussed in "Ultraviolet Photometry from the Orbiting Astronomical Observatory. VIII. The Blue Ap Stars" by D. S. Leckrone, Astrophysical Journal, 185, 577, October 1973. Note that these figures are provisional and are the best available as of the date in the lower right-hand corner of the page.

Summary of Performance Characteristics of Stellar Photometers and Filters

Stellar Photometer 1 (ST1) overall: The presence of red leaks had little effect on this photometer because the interference filters were all in or near the visual region. The digital counter malfunctioned in the vicinity of Orbits 3000 to 4000 and around Orbits 15,000 and 18,500. Filter degradations appear to be spectrum-independent. For further information, see the article by Bendell in the OAO 2 symposium.

ST1 F1 (3317 A): This filter was particularly well suited to observing late-type stars, as the filter response was defined by both the UG11 glass and the interference filter.
ST1 F2 (dark): No comments.
ST1 F3 (4252 A): This was a good filter.
ST1 F4 (2985 A): A pinhole leak in this filter caused it to yield an abnormally large signal occasionally.

Stellar Photometer 2 (ST2) overall: Pinholes in the filters had little effect at short wavelengths due to the EMI photomultiplier tube cutoff and the fused quartz cutoff.

ST2 F1 (2035 A): Data from this filter are unreliable for late-type stars. The filter was very sensitive to red leaks at long wavelengths (more so than ST2 F5). One-half of the filter was 10 times as transparent as the other half. This problem is not noticeable, however, in the data from early-type stars.
ST2 F2 (2945 A): Data from this filter also are unreliable for late-type objects. The filter was somewhat sensitive to red leaks at long wavelengths but less so than ST2 F5.
ST2 F3 (dark): No comments.
ST2 F4 (cal.): No comments.
ST2 F5 (2386 A): Data from this filter are very bad for late-type objects as the filter was very sensitive to red leaks at long wavelengths. For solar-type spectra, a 0.001 red leak would produce a response equal to that expected from the 2386 ± 330-A passband.

Stellar Photometer 3 (ST3) overall: Red leaks in the photometer had little effect, owing to the long-wavelength cutoff characteristics of the ASCOP photomultiplier tube. However, the CaF_2 substrates fluoresced due to the calibration source. Bias counts, therefore, appear in the observations. Filter degradation showed a variation with spectral type.

ST3 F1 (1913 A): This filter was well suited for late-type star observations. The ASCOP tube eliminated the effects of red leaks, and the suprasil substrate eliminated the effect of Lyman-Alpha leaks at short wavelengths. Filter bias was 0.5 count at E4 (64 seconds).
ST3 F2 (2462 A): This filter was well suited for late-type star observations. The ASCOP tube eliminated the effects of red leaks, and the suprasil substrate eliminated the effect of Lyman-Alpha leaks at short wavelengths. Filter bias was 5.3 count at E4 (64 seconds).
ST3 F3 (cal.): No comments.
ST3 F4 (dark): Filter bias was 6.8 counts at E4 (64 seconds).
ST3 F5 (1679 A): Data from this filter are unreliable and should not be used. The filter bias was 34.8 counts at E4 (64 seconds). One-half of the filter transmitted twice as much as the other half for all wavelengths.

Stellar Photometer 4 (ST4) overall: Red leaks in the photometer had little effect on the data, owing to the long-wavelength cutoff characteristics of the ASCOP photomultiplier tube. However, the CaF_2 substrates fluoresced due to the calibration source, and bias counts, therefore, appear in the observations. Filter degradation showed a variation with spectral type.

ST4 F1 (1554 A): This filter was well suited for observations of late-type stars. Its passband was defined by the ASCOP tube and the CaF_2 substrate, as well as by the interference filter. Without the interference filter, the effective wavelength remained the same while the passband increased by about 100 A. Filter bias for the interference filter was 10.4 counts at E4 (64 seconds).
ST4 F2 (cal.): No comments.
ST4 F3 (1430 A): Filter bias was 10.8 counts at E4 (64 seconds).
ST4 F4 (1332 A): Filter bias was 2.0 counts at E4 (64 seconds). The transmission peaks near Lyman-Alpha wavelength.
ST4 F5 (dark): Filter bias was 1.0 at E4 (64 seconds).

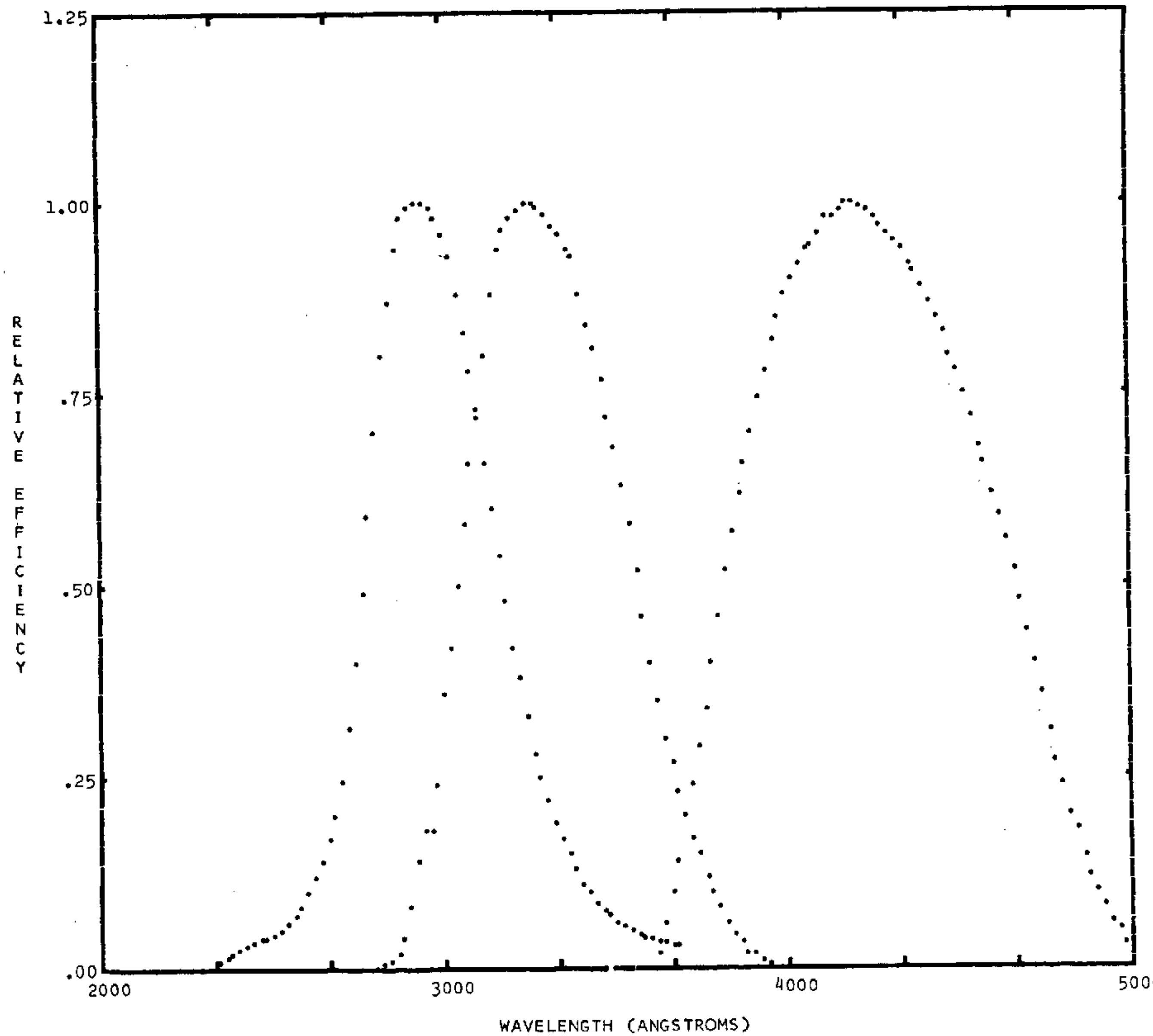

Figure 2.1-1. Stellar Photometer 1, Filter Relative Efficiencies (Prelaunch)

Table 2.1-1

Stellar Photometer 1, Filter Relative Efficiencies (Prelaunch)

============ *S1F1* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
2800	.001	3500	.680
2820	.005	3520	.630
2839	.010	3540	.580
2860	.020	3560	.520
2879	.040	3580	.460
2900	.080	3600	.400
2919	.140	3620	.350
2939	.180	3640	.300
2960	.180	3659	.270
2979	.240	3680	.230
3000	.360	3700	.200
3020	.420	3720	.170
3040	.500	3740	.150
3060	.580	3759	.120
3080	.660	3780	.100
3100	.730	3799	.080
3120	.800	3820	.060
3140	.880	3840	.045
3160	.940	3859	.033
3180	.965	3880	.020
3199	.980	3899	.017
3220	.990	3920	.010
3240	.999	3939	.005
3260	.999		
3280	.995		
3299	.985		
3320	.970		
3339	.960		
3360	.940		
3380	.930		
3399	.880		
3420	.840		
3439	.810		
3460	.770		
3479	.720		

============ *S1F3* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
3620	.020	4319	.950
3640	.060	4339	.940
3659	.100	4359	.920
3680	.140	4379	.910
3700	.200	4399	.890
3720	.240	4419	.870
3740	.290	4440	.850
3759	.340	4459	.830
3780	.400	4480	.800
3799	.460	4500	.780
3820	.520	4519	.750
3840	.570	4540	.720
3859	.620	4559	.680
3880	.660	4580	.660
3899	.701	4599	.620
3920	.744	4620	.590
3939	.780	4639	.560
3959	.820	4660	.520
3980	.850	4679	.480
4000	.880	4700	.440
4020	.900	4719	.400
4040	.920	4740	.359
4059	.940	4759	.310
4080	.946	4779	.270
4099	.962	4799	.240
4120	.980	4819	.200
4139	.982	4839	.178
4160	.990	4860	.142
4179	1.000	4879	.120
4200	.999	4900	.100
4219	.995	4919	.080
4240	.990	4940	.060
4259	.980	4959	.050
4280	.970	4979	.030
4299	.960	5000	.020

============ *S1F4* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
2339	.010	3040	.880
2359	.015	3060	.830
2379	.020	3080	.780
2399	.024	3100	.720
2419	.028	3120	.660
2439	.032	3140	.600
2459	.038	3160	.540
2479	.040	3180	.480
2500	.044	3199	.420
2520	.050	3220	.380
2540	.060	3240	.330
2560	.070	3260	.280
2580	.080	3280	.250
2600	.097	3299	.220
2620	.120	3320	.190
2639	.140	3339	.170
2660	.170	3360	.150
2680	.200	3380	.130
2700	.245	3399	.110
2720	.315	3420	.100
2739	.400	3439	.085
2760	.490	3460	.075
2779	.590	3479	.068
2800	.700	3500	.060
2820	.800	3520	.055
2839	.870	3540	.050
2860	.940	3560	.045
2879	.980	3580	.041
2900	.995	3600	.039
2919	1.000	3620	.036
2939	1.000	3640	.032
2960	.995	3660	.031
2979	.980	3680	.030
3000	.960		
3020	.930		

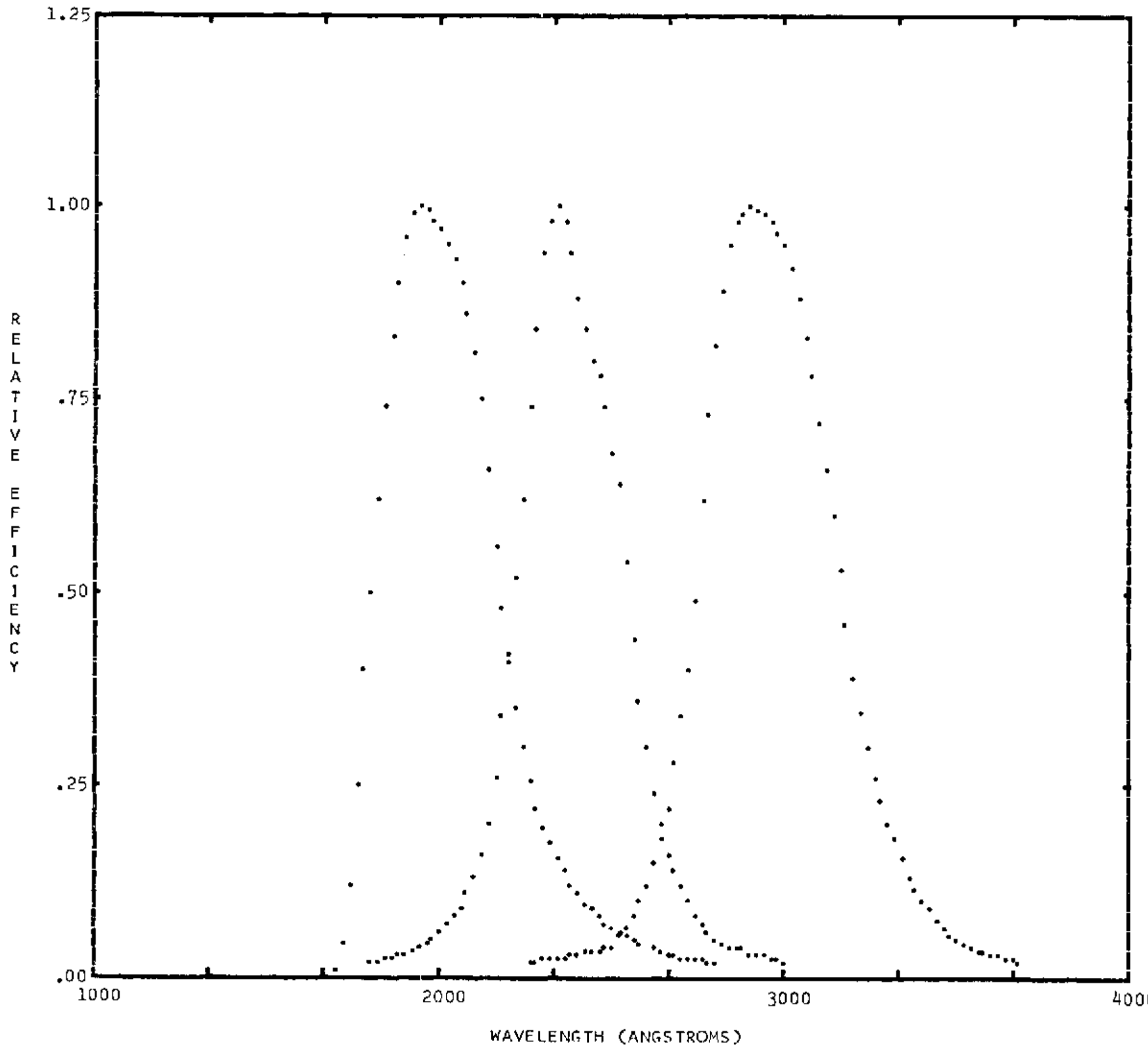

Figure 2.1-2 Stellar Photometer 2, Filter Relative Efficiencies (Prelaunch)

Table 2.1-2

Stellar Photometer 2, Filter Relative Efficiencies (Prelaunch)

============ *S2F1* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1699	.010	2419	.095
1719	.045	2439	.087
1739	.120	2459	.078
1760	.250	2479	.070
1780	.400	2500	.063
1800	.500	2520	.058
1820	.620	2540	.052
1840	.740	2560	.048
1860	.830	2580	.043
1879	.900	2600	.040
1899	.960	2620	.037
1920	.990	2639	.033
1940	1.000	2660	.031
1960	.996	2680	.028
1979	.980	2700	.025
2000	.970	2720	.024
2020	.950	2739	.023
2040	.930	2760	.022
2060	.900	2779	.021
2080	.860	2800	.020
2100	.810		
2120	.750		
2140	.660		
2159	.560		
2179	.480		
2199	.410		
2220	.350		
2240	.300		
2259	.253		
2279	.220		
2299	.195		
2319	.175		
2339	.155		
2359	.138		
2379	.120		
2399	.110		

============ *S2F2* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
2259	.020	2979	.965
2279	.020	3000	.950
2299	.022	3020	.920
2319	.023	3040	.880
2339	.025	3060	.830
2359	.026	3080	.780
2379	.028	3100	.720
2399	.030	3120	.660
2419	.033	3140	.600
2439	.034	3160	.530
2459	.036	3180	.460
2479	.038	3199	.390
2500	.040	3220	.345
2520	.052	3240	.300
2540	.065	3260	.260
2560	.080	3280	.230
2580	.100	3299	.200
2600	.120	3320	.180
2620	.150	3339	.155
2639	.180	3360	.130
2660	.220	3380	.115
2680	.280	3399	.100
2700	.340	3420	.088
2720	.400	3439	.075
2739	.490	3460	.065
2760	.620	3479	.055
2779	.730	3500	.050
2800	.820	3520	.045
2820	.890	3540	.040
2839	.950	3560	.035
2860	.980	3580	.032
2879	.990	3600	.030
2900	1.000	3620	.028
2919	.995	3640	.024
2939	.990	3660	.022
2960	.980	3680	.020

============ *S2F5* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1800	.020	2520	.640
1820	.020	2540	.540
1840	.022	2560	.440
1860	.025	2580	.360
1879	.029	2600	.300
1899	.030	2620	.240
1920	.035	2639	.200
1940	.040	2660	.160
1960	.045	2680	.140
1979	.050	2700	.120
2000	.060	2720	.100
2020	.070	2739	.080
2040	.079	2760	.070
2060	.090	2779	.060
2080	.110	2800	.050
2100	.130	2820	.045
2120	.160	2839	.040
2140	.200	2860	.039
2159	.260	2879	.038
2179	.340	2900	.030
2199	.420	2919	.030
2220	.520	2939	.029
2240	.620	2960	.025
2259	.740	2979	.022
2279	.840	3000	.020
2299	.940		
2319	.980		
2339	1.000		
2359	.980		
2379	.940		
2399	.880		
2419	.840		
2439	.800		
2459	.780		
2479	.740		
2500	.680		

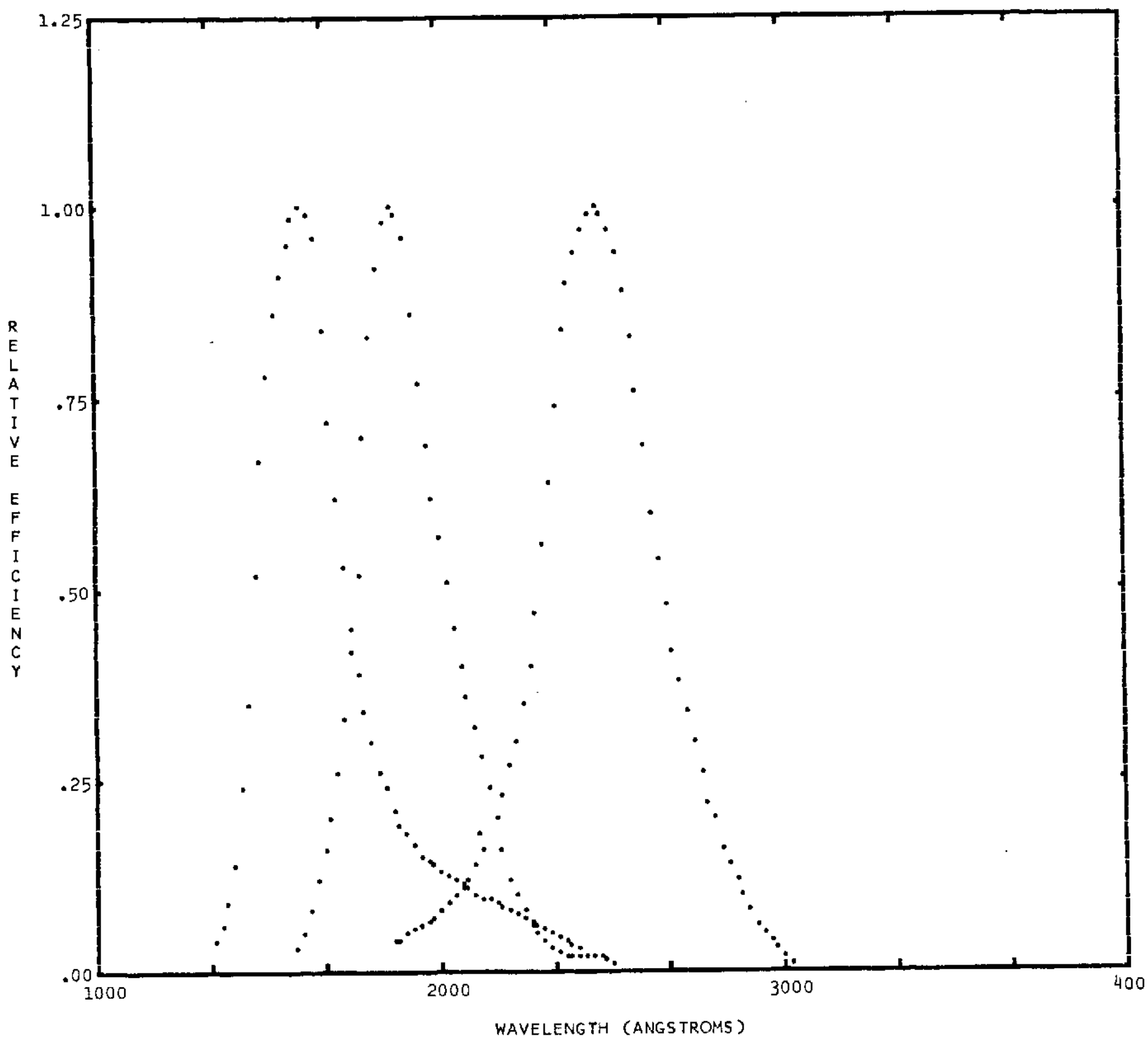

Figure 2.1-3. Stellar Photometer 3, Filter Relative Efficiencies (Prelaunch)

Table 2.1-3

Stellar Photometer 3, Filter Relative Efficiencies (Prelaunch)

============ *S3F1* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1580	.030	2179	.160
1599	.050	2199	.120
1620	.080	2220	.100
1640	.120	2240	.080
1660	.160	2259	.060
1680	.200	2279	.050
1699	.260	2299	.040
1719	.330	2319	.030
1739	.420	2339	.025
1760	.520	2359	.020
1780	.700	2379	.020
1800	.830	2399	.020
1820	.920	2419	.019
1840	.980	2439	.018
1860	1.000	2459	.017
1879	.990	2479	.015
1899	.960	2500	.010
1920	.860		
1940	.770		
1960	.690		
1979	.620		
2000	.570		
2020	.510		
2040	.450		
2060	.400		
2080	.360		
2100	.320		
2120	.280		
2140	.240		
2159	.200		

============ *S3F2* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1860	.040	2459	1.000
1879	.040	2479	.990
1899	.050	2500	.970
1920	.055	2520	.940
1940	.060	2540	.890
1960	.063	2560	.830
1979	.070	2580	.760
2000	.080	2600	.690
2020	.090	2620	.600
2040	.100	2639	.540
2060	.110	2660	.480
2080	.120	2680	.420
2100	.140	2700	.380
2120	.160	2720	.340
2140	.180	2739	.300
2159	.200	2760	.260
2179	.230	2779	.220
2199	.270	2800	.199
2220	.300	2820	.160
2240	.350	2839	.140
2259	.400	2860	.120
2279	.470	2879	.100
2299	.560	2900	.080
2319	.640	2919	.060
2339	.740	2939	.050
2359	.840	2960	.040
2379	.900	2979	.030
2399	.940	3000	.020
2419	.970	3020	.010
2439	.990		

============ *S3F5* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1340	.040	1940	.150
1360	.060	1960	.146
1380	.090	1979	.140
1400	.140	2000	.130
1419	.240	2020	.125
1439	.350	2040	.120
1459	.520	2060	.115
1480	.670	2080	.110
1500	.780	2100	.100
1520	.860	2120	.095
1540	.910	2140	.092
1560	.950	2159	.090
1580	.985	2179	.085
1599	1.000	2199	.080
1620	.990	2220	.075
1640	.960	2240	.070
1660	.840	2259	.065
1680	.720	2279	.060
1699	.620	2299	.055
1719	.530	2319	.050
1739	.450	2339	.045
1760	.390	2359	.040
1780	.340	2379	.035
1800	.300	2399	.030
1820	.260		
1840	.240		
1860	.210		
1879	.190		
1899	.180		
1920	.165		

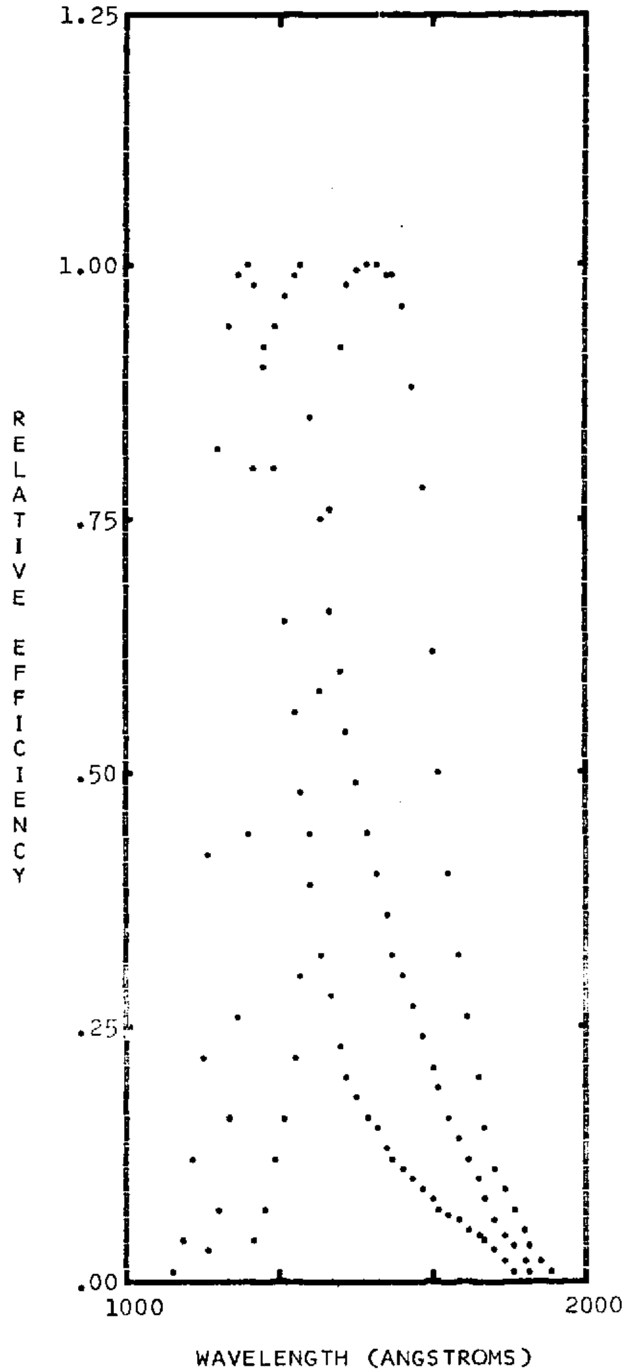

Figure 2.1-4. Stellar Photometer 4, Filter Relative Efficiencies (Prelaunch)

Table 2.1-4

Stellar Photometer 4, Filter Relative Efficiencies (Prelaunch)

============ *S4F1* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1280	.040	1660	.620
1300	.070	1680	.500
1319	.120	1699	.400
1340	.160	1719	.320
1360	.220	1739	.260
1380	.300	1760	.200
1400	.440	1780	.150
1419	.580	1800	.110
1439	.760	1820	.090
1459	.920	1840	.070
1480	.980	1860	.050
1500	.995	1879	.034
1520	1.000	1899	.020
1540	1.000	1920	.010
1560	.993		
1580	.990		
1599	.960		
1620	.880		
1640	.780		

============ *S4F3* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1179	.030	1560	.360
1199	.070	1580	.320
1219	.160	1599	.300
1239	.260	1620	.270
1260	.440	1640	.240
1280	.800	1660	.210
1300	.900	1680	.190
1319	.940	1699	.160
1340	.970	1719	.140
1360	.990	1739	.120
1380	1.000	1760	.100
1400	.850	1780	.080
1419	.750	1800	.060
1439	.660	1820	.042
1459	.600	1840	.032
1480	.540	1860	.020
1500	.490	1879	.010
1520	.440		
1540	.400		

============ *S4F4* ============

WAVE.	*R.EFF.*	*WAVE.*	*R.EFF.*
1099	.010	1480	.200
1120	.040	1500	.180
1139	.120	1520	.160
1159	.220	1540	.150
1179	.420	1560	.130
1199	.820	1580	.120
1219	.940	1599	.110
1239	.990	1620	.100
1260	1.000	1640	.090
1280	.980	1660	.080
1300	.920	1680	.070
1319	.800	1699	.065
1340	.650	1719	.060
1360	.560	1739	.050
1380	.480	1760	.045
1400	.390	1780	.040
1419	.320	1800	.030
1439	.280	1820	.020
1459	.230	1840	.010

Table 2.1-5

Bandpass Characteristics of OAO 2/WEP Photometers

Stellar Photometer	Photomultiplier (passband, A)	Filter Number	Filter Type	Effective Wavelength for Flat Spectrum (A)	Wavelength Limits at 0.5 Maximum Sensitivity	Mnemonic
1	EMI 6256B, CsAn (1700 - 6000)	1	I.F. + UG11	3317	3040-3560	ST1 F1, S1F1
		2	Dark	---	---	ST1 F2, S1F2
		3	BG12 GG13	4252	3810-4670	ST1 F3, S1F3
		4	I.F. F.Q.	2985	2760-3170	ST1 F4, S1F4
		5	Calibration	---	---	ST1 F5, S1F5
2	EMI 6256B, CsAn (1700 - 6000)	1	I.F. + F.Q.	2035	1690-2180	ST2 F1, S2F1
		2	I.F. + F.Q.	2945	2740-3170	ST2 F2, S2F2
		3	Dark	---	---	ST2 F3, S2F3
		4	Calibration	---	---	ST2 F4, S2F4
		5	I.F. + F.Q.	2386	2220-2550	ST2 F5, S2F5

Note: I.F. refers to an interference filter operating in the first order. No other transmission bands can be detected by the photomultiplier.

Table 2.1-5 (continued)

Stellar Photometer	Photomultiplier (passband, A)	Filter Number	Filter Type	Effective Wavelength for Flat Spectrum (A)	Wavelength Limits at 0.4 Maximum Sensitivity	Mnemonic
3	Ascop 541F, Cst LiF Window (1050 - 3500)	1	I.F. + F.Q.	1913	1760-2020	ST3 F1, S3F1
		2	I.F. + F.Q.	2462	2290-2650	ST3 F2, S3F2
		3	Calibration	---	---	ST3 F3, S3F3
		4	Dark	---	---	ST3 F4, S3F4
		5	I.F. + CaF_2	1679	1460-1730	ST3 F5, S3F5
4	Ascop 541G, CsI (1050 - 1950)	1	I.F. + CaF_2	1554	1410-1680	ST4 F1, S4F1
		2	Calibration	---	---	ST4 F2, S4F2
		3	I.F. + CaF_2	1430	1260-1500	ST4 F3, S4F3
		4	I.F. + LiF_2	1332	1185-1370	ST4 F4, S4F4
		5	Dark	---	---	ST4 F5, S4F5

Note: I.F. refers to an interference filter operating in the first order. No other transmission bands can be detected by the photomultiplier.

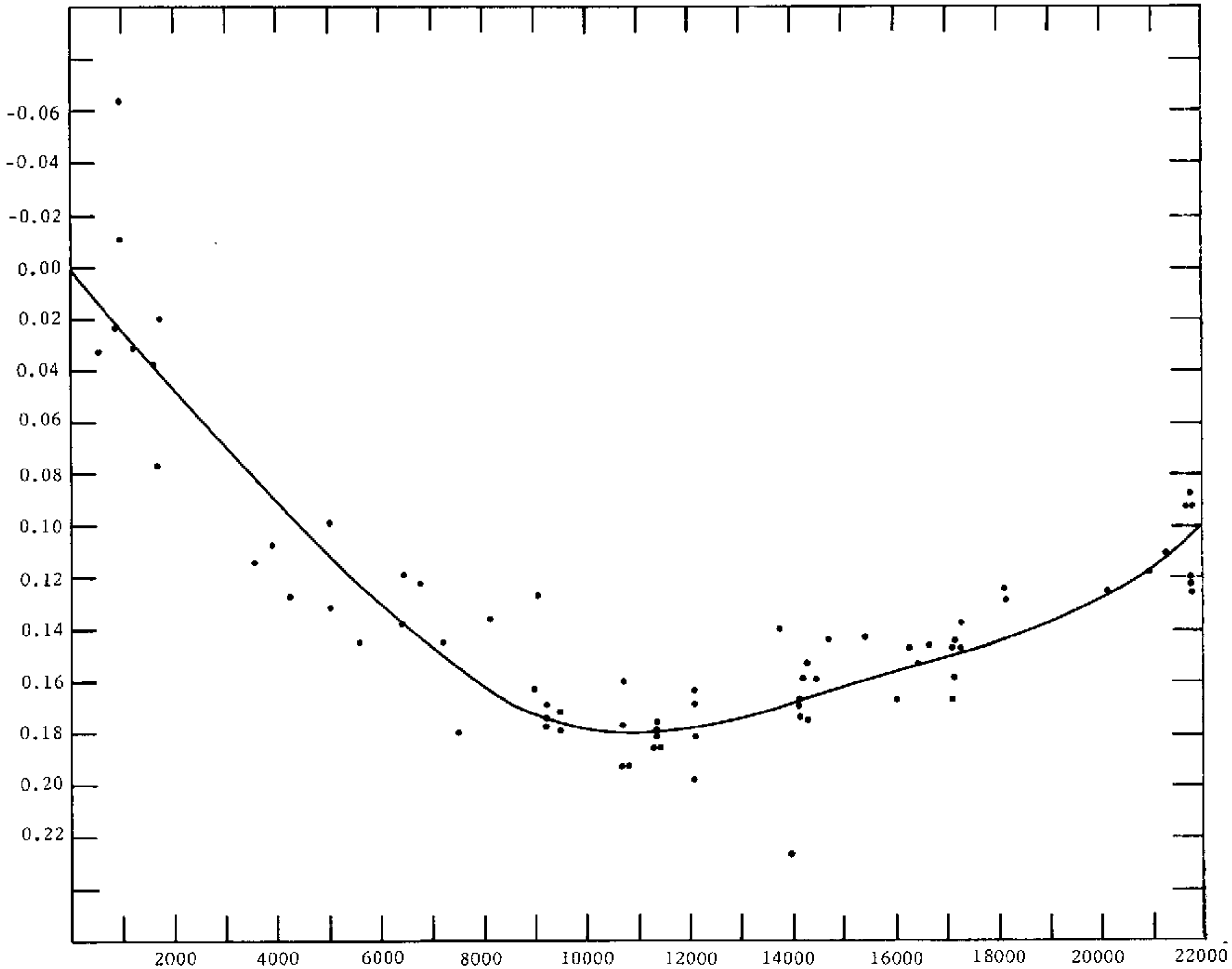

Figure 2.1-5. ST1 F1 Degradation

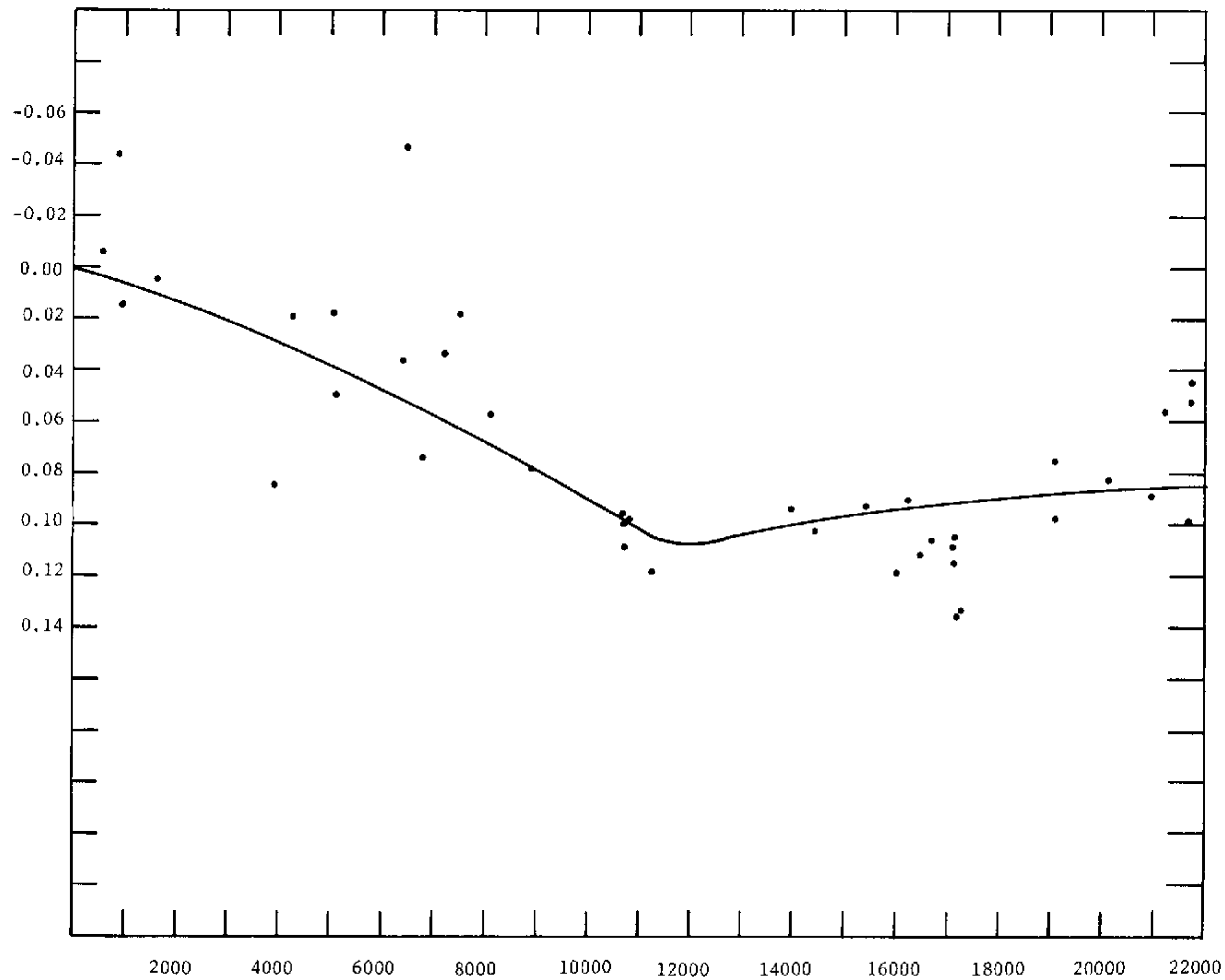

Figure 2.1-6. ST1 F3 Degradation

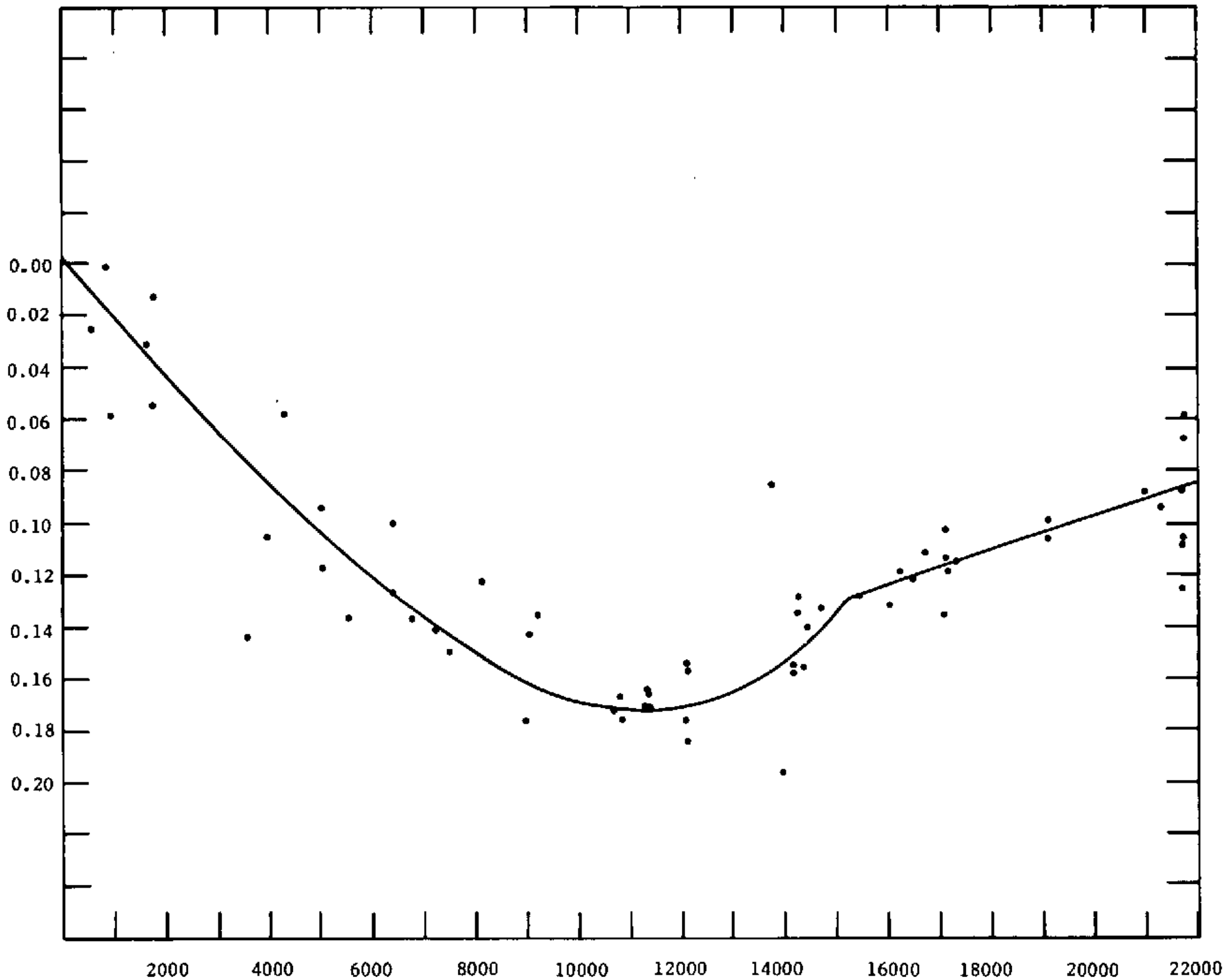

Figure 2.1-7. ST1 F4 Degradation

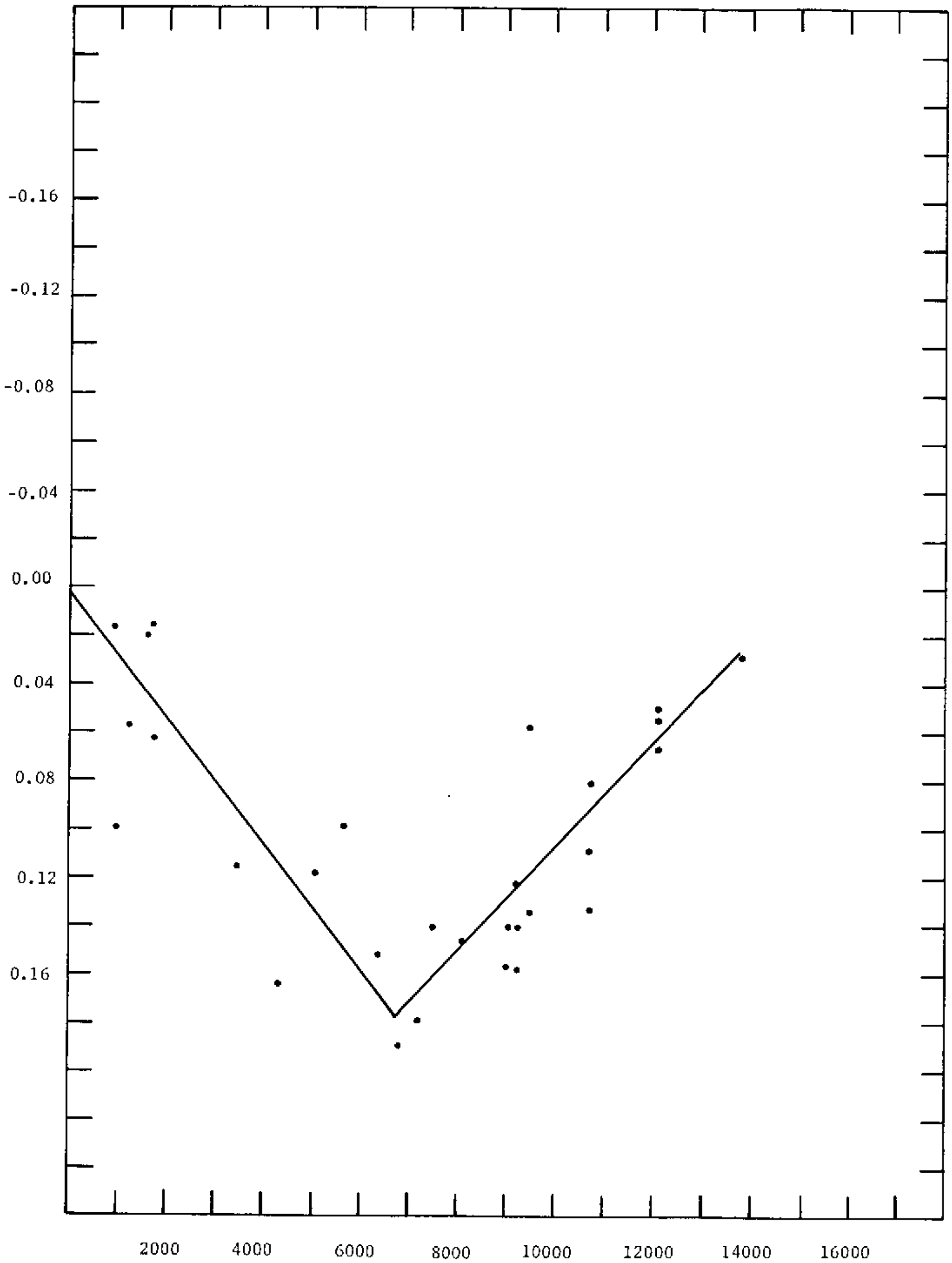

Figure 2.1-8. ST2 F1 Degradation

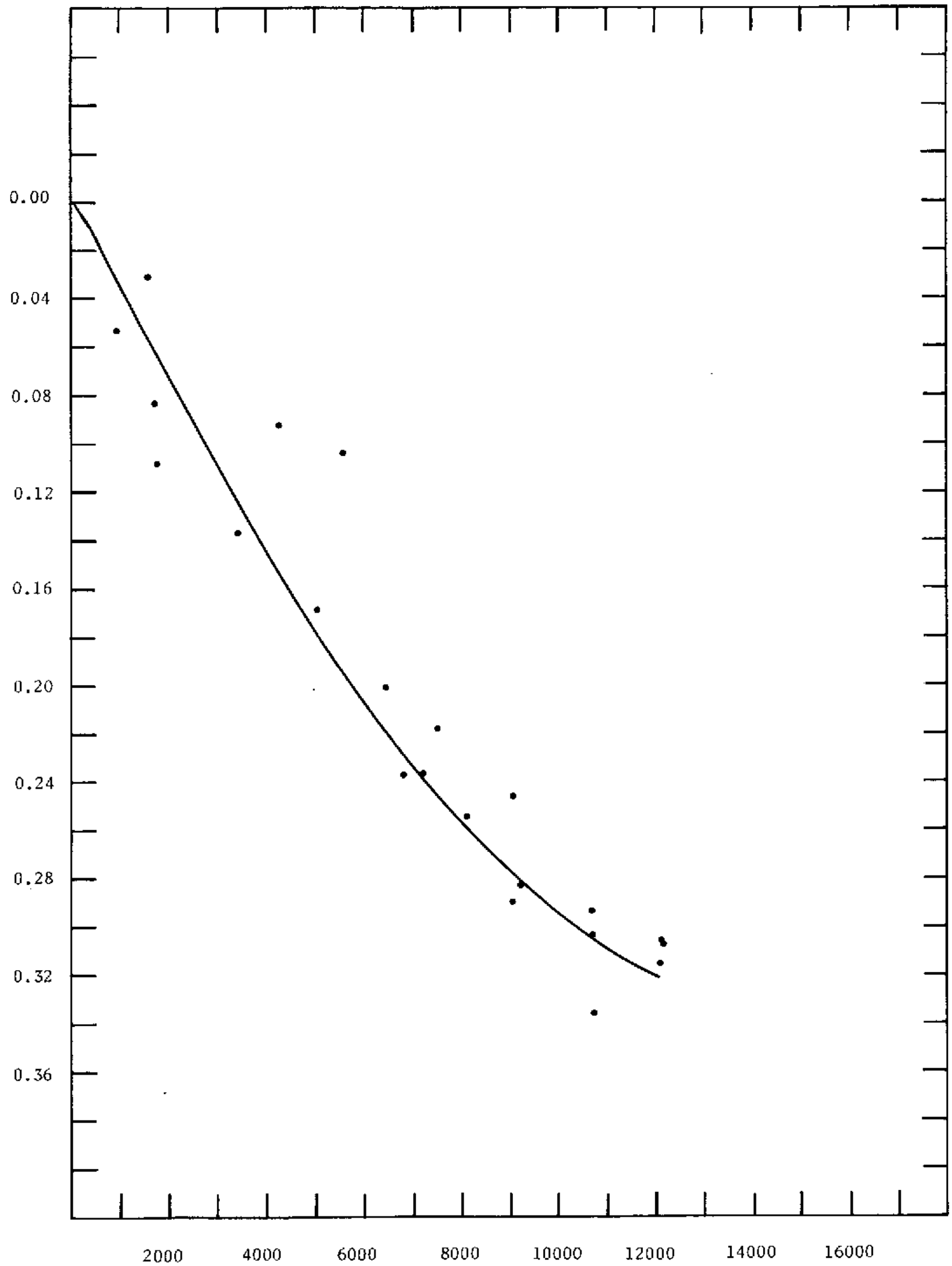

Figure 2.1-9. ST2 F2 Degradation

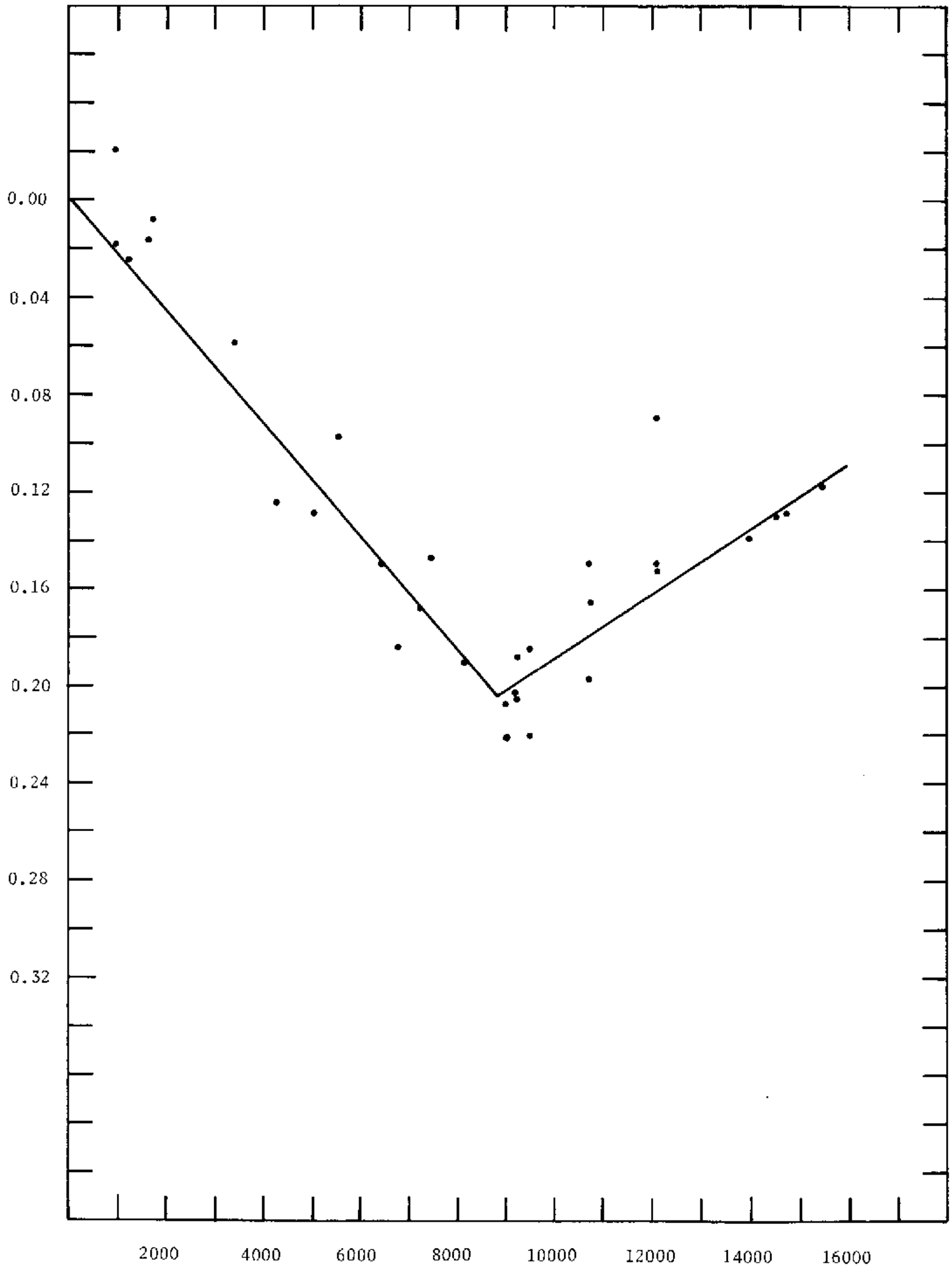

Figure 2.1-10. ST2 F5 Degradation

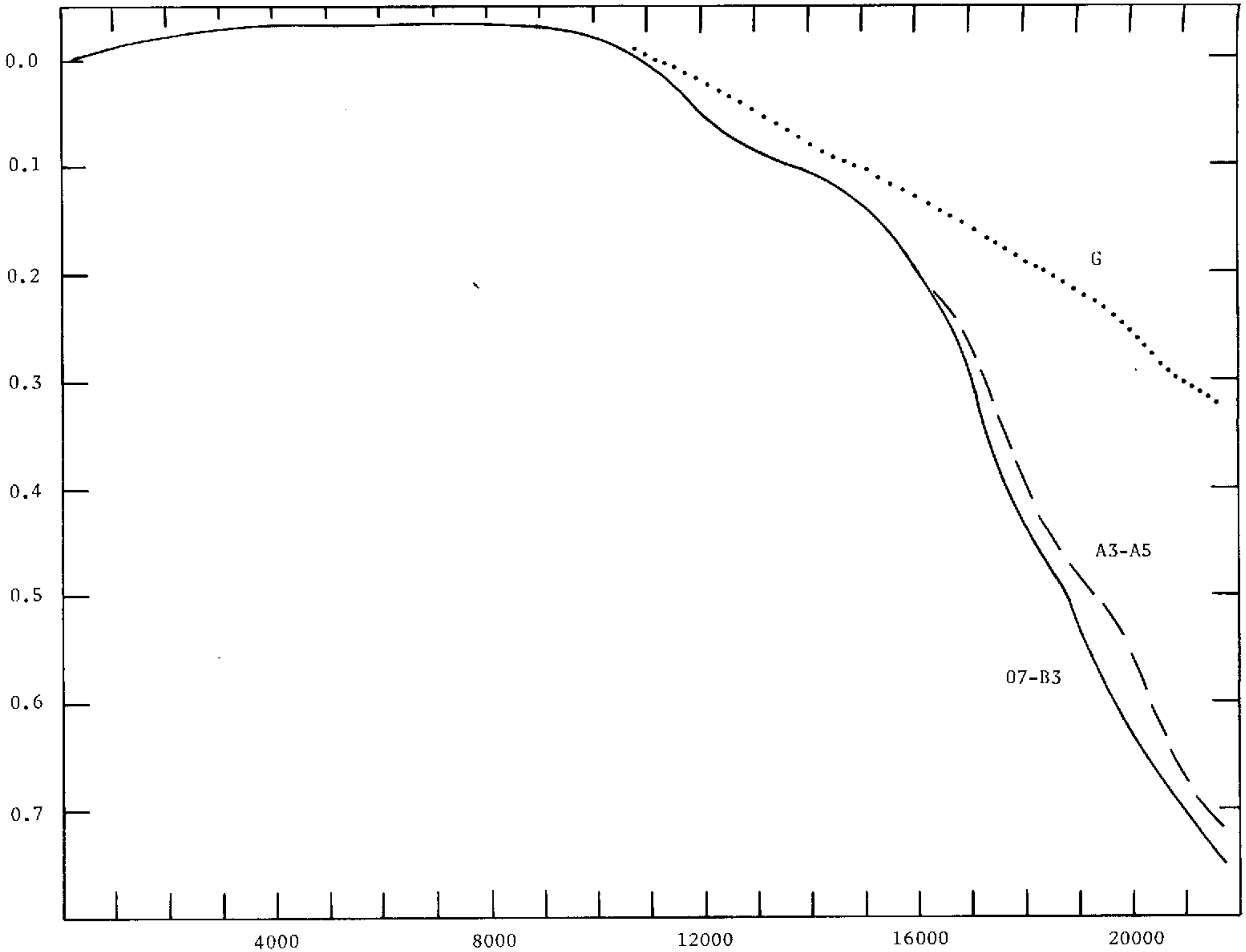

Figure 2.1-11. ST3 F1 Degradation

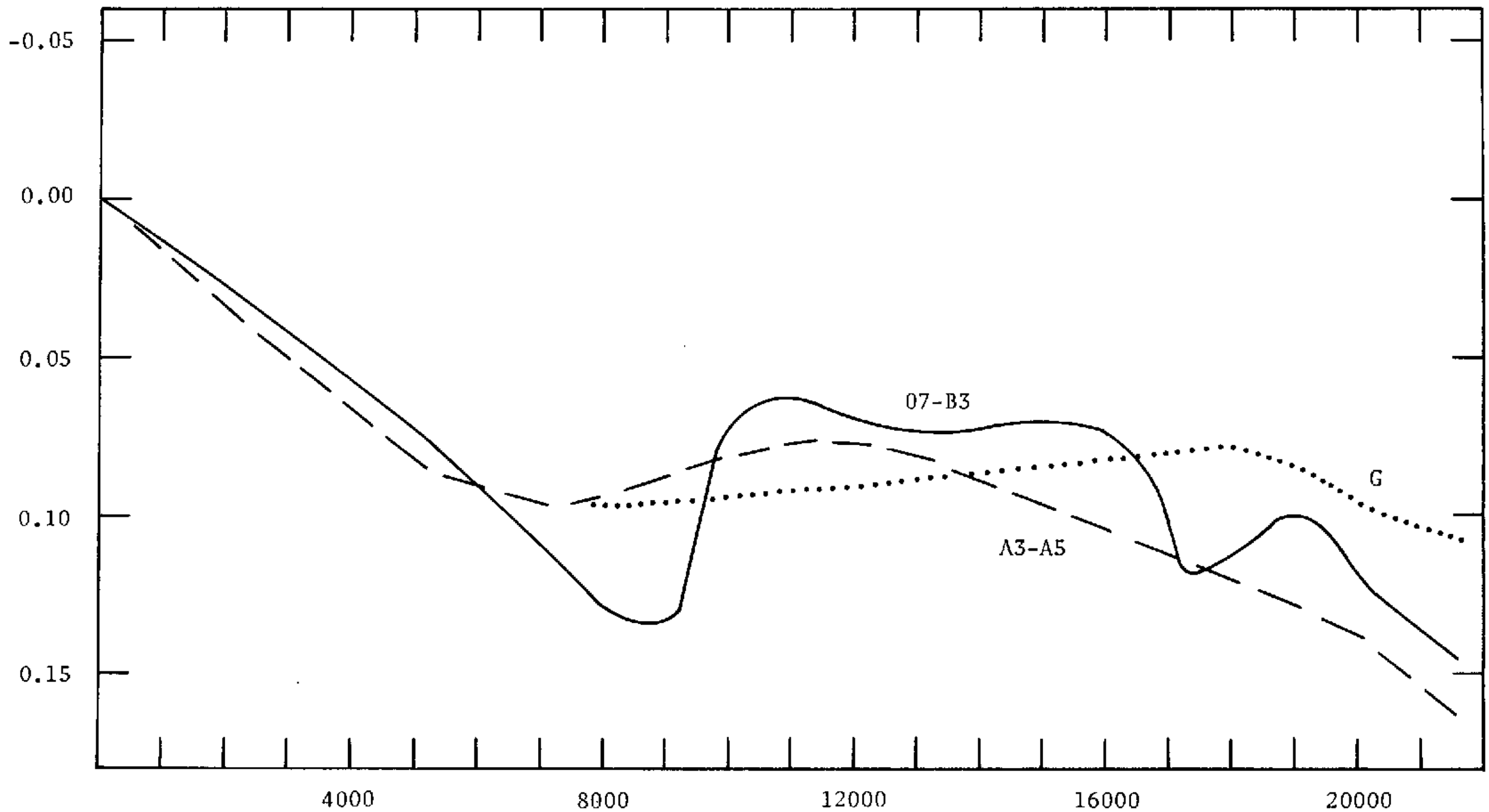

Figure 2.1-12. ST3 F2 Degradation

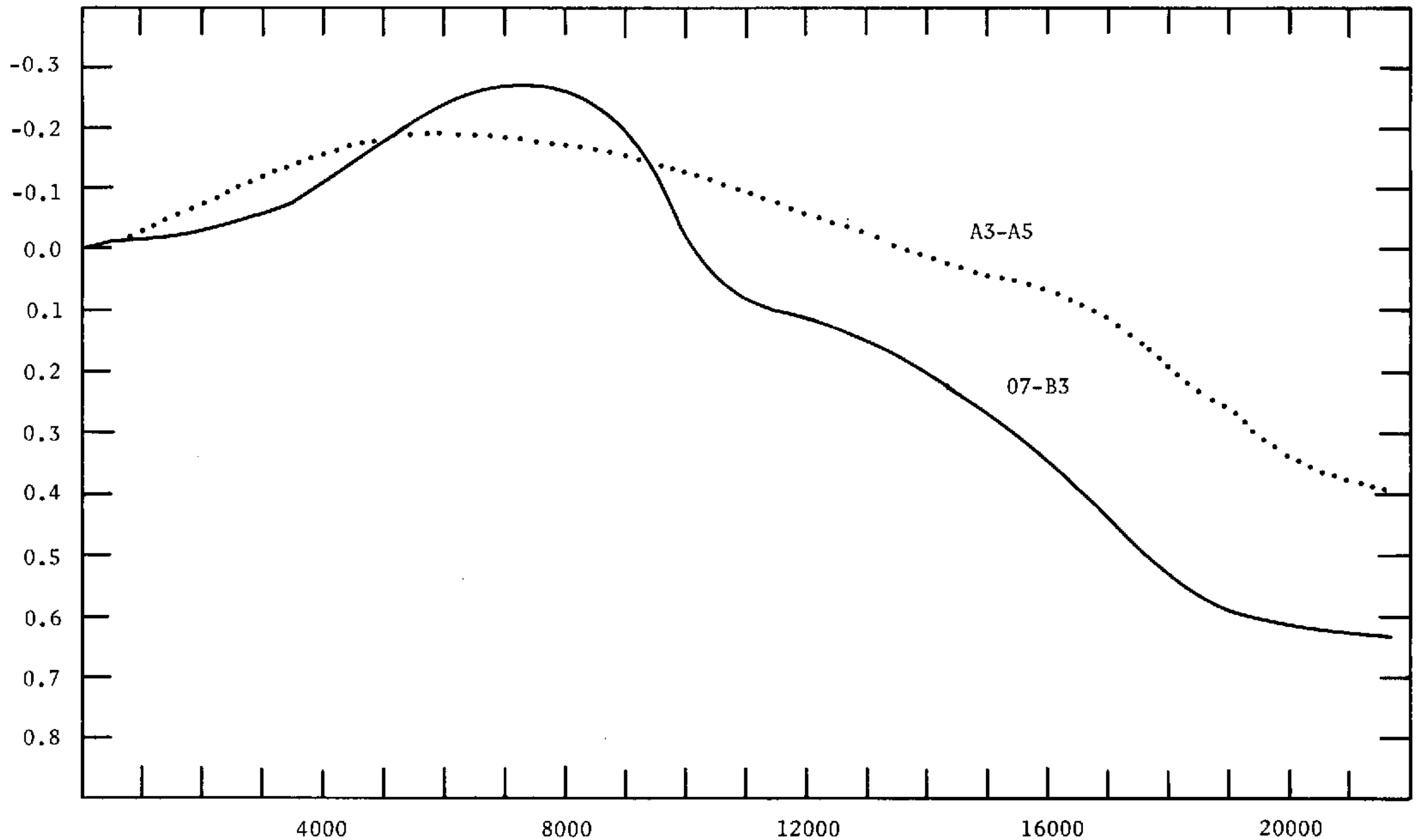

Figure 2.1-13. ST3 F5 Degradation

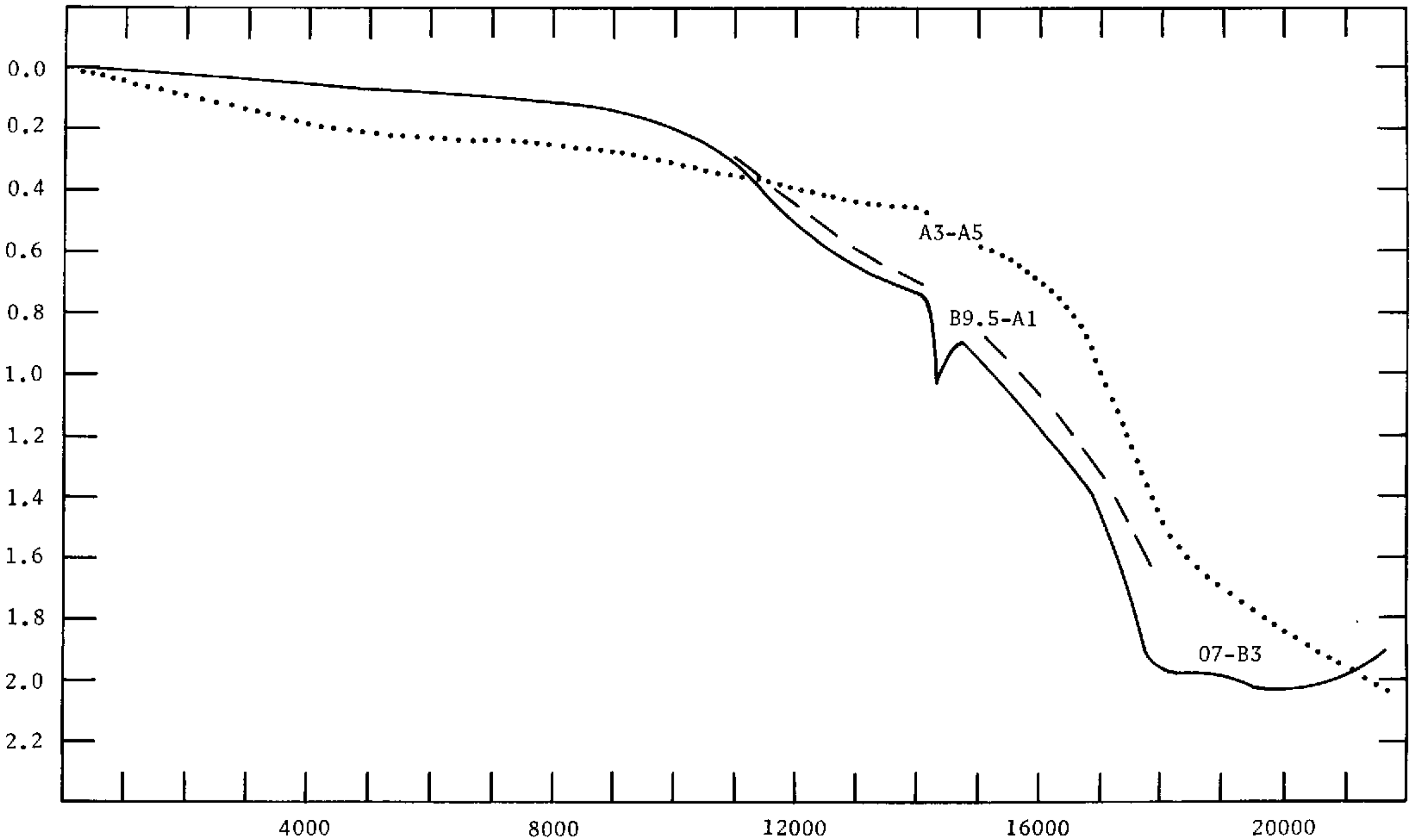

Figure 2.1-14. ST4 F1 Degradation

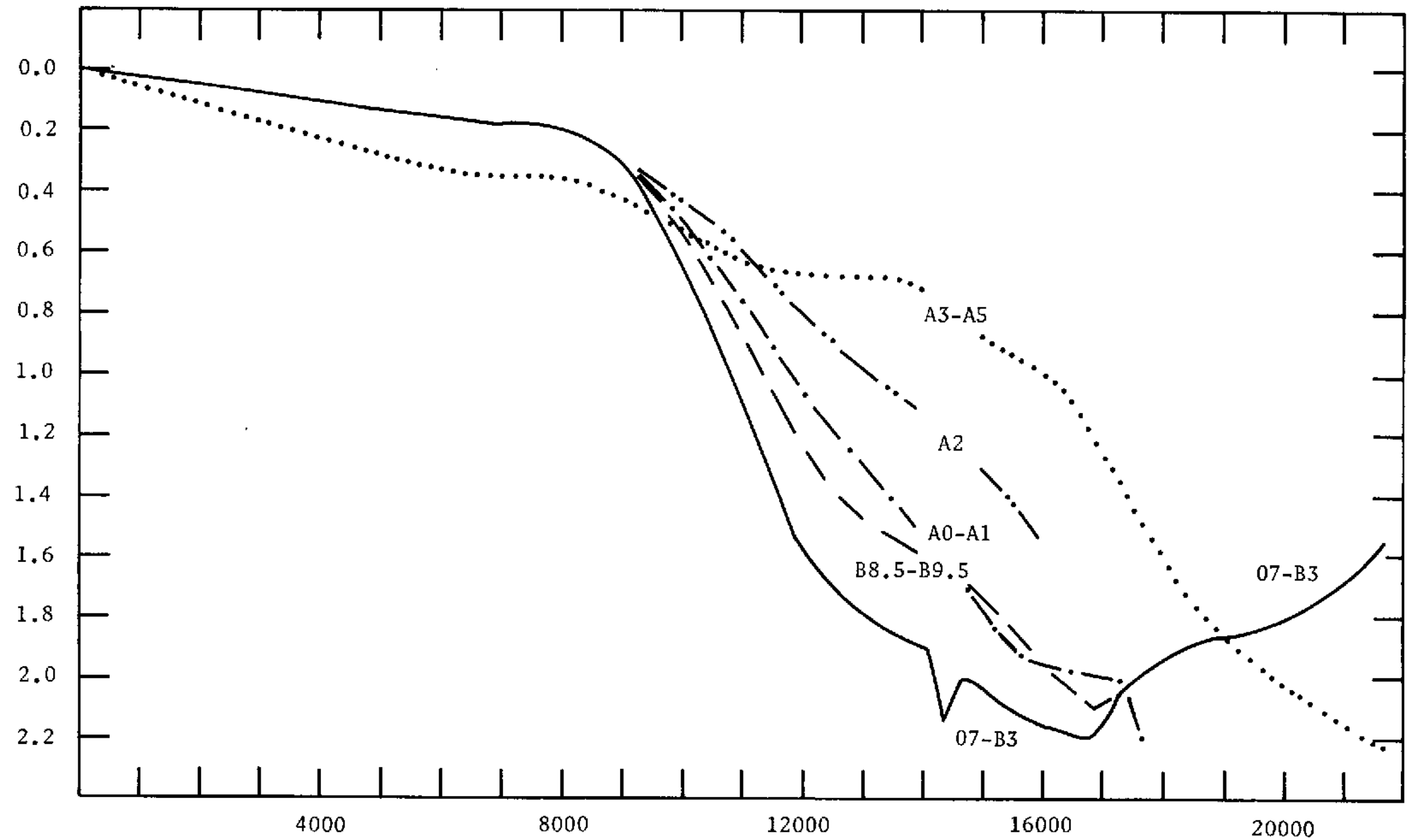

Figure 2.1-15. ST4 F3 Degradation

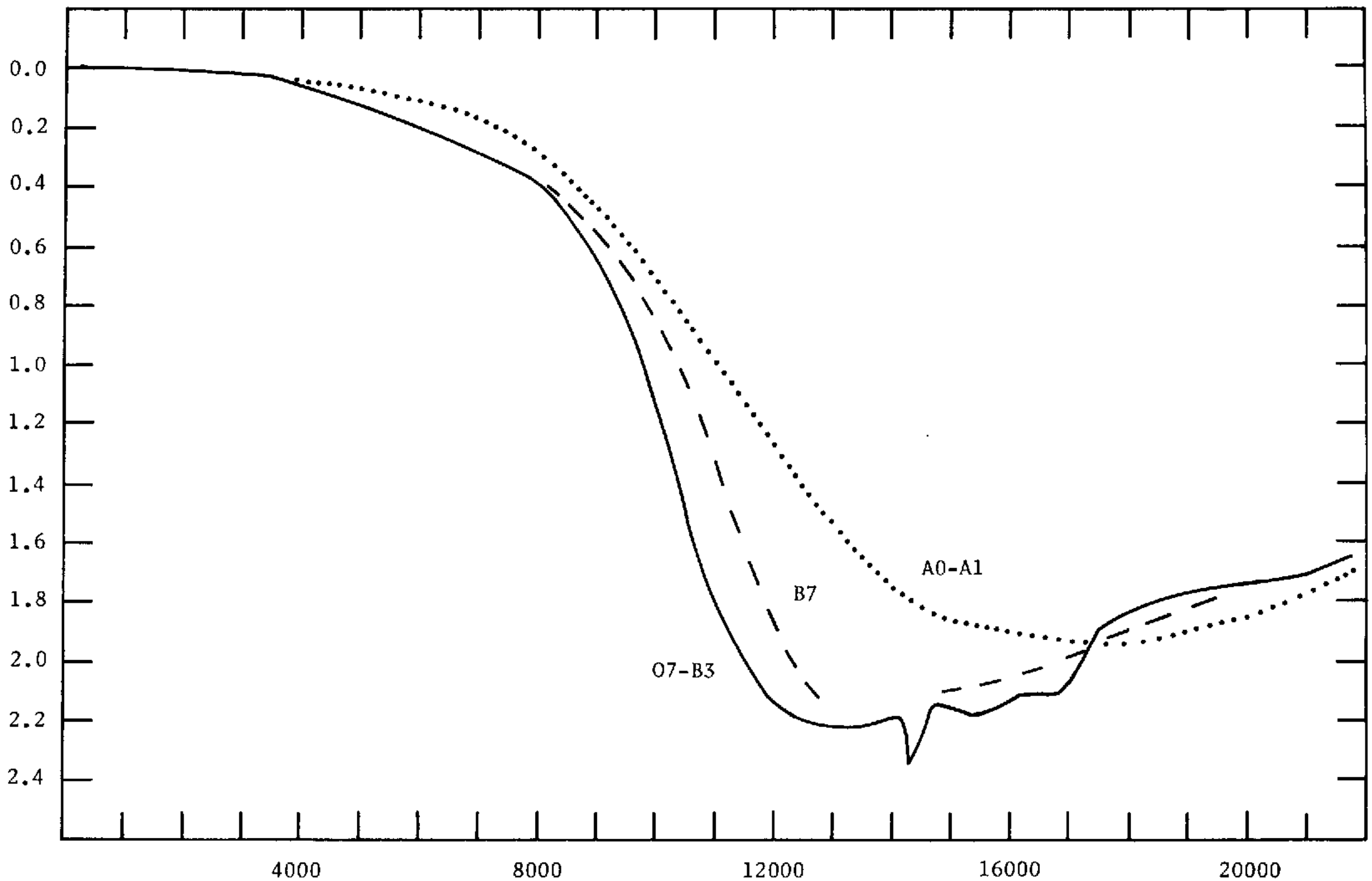

Figure 2.1-16. ST4 F4 Degradation

2.2 ELECTRONICS SYSTEM

Signals from individual photomultipliers were sent to the pulse amplifiers as input to the digital system and to electrometer amplifiers as input to the analog system. The overall electronics system is schematically diagrammed in Figure 2.2-1. At the end of an exposure time (see Table 2.2-1), the voltage across the load resistor was amplified by the electrometer amplifier and sampled with an A/D converter. The result was placed in spacecraft storage. The voltages ranged from zero to 5.04 volts, with the basic encoder quantum being 0.020 volt (20 millivolts). Thus, the normal error for these measurements is 1 quantum of 20 millivolts. The electrometer amplifiers had d.c. offsets of approximately 0.1 volt, although these offsets drifted slowly and some amplifiers acquired negative offsets. The analog amplifier of Stellar Photometer 4 did <u>not</u> function.

Photomultiplier output pulses were amplified by a pulse amplifier and detected by a threshold detector. They were then divided by 64 (prescaled), and the resulting counts were accumulated in data registers for the exposure time determined by the gain. A maximum of 255 counts could be accumulated by each data register before it overflowed. The number of digital register overflows can be determined only from the analog voltage. An additional bias arises in that an additional count was added to the accumulator if it was gated off when the prescaler was more than half full. Also, at large count rates the dead time in the counters caused a loss of some counts. Deadtime corrections to ST1 E1 and ST3 E2 can be made from the curves shown in Figures 4.3-1 and 4.3-2. These deadtime corrections can be applied analytically using the formula:

$$\text{Counts(true)} = A + (B \times \text{counts(apparent)}) + (C \times \text{counts(apparent)}^2) + (D \times \text{counts(apparent)}^3). \quad (2.2\text{-}1)$$

The formula holds for apparent counts above 600 (with ST1 E1) and between 1200 and 8000 (with ST3 E2), and where:

$A = -7.5$	(ST1 E1)	or	34.135	(ST3 E2),
$B = 1.12022$	(ST1 E1)	or	0.915744	(ST3 E2),
$C = -0.0003556$	(ST1 E1)	or	4.04533×10^{-5}	(ST3 E2), and
$D = 2.94 \times 10^{-7}$	(ST1 E1)	or	5.05502×10^{-9}	(ST3 E2).

The root-mean-square error derived from using this formula is about 2 percent for ST1 E1 and 3 percent for ST3 E2. These errors are of the same order of magnitude as the uncertainty in the data from which the analytic expressions were derived.

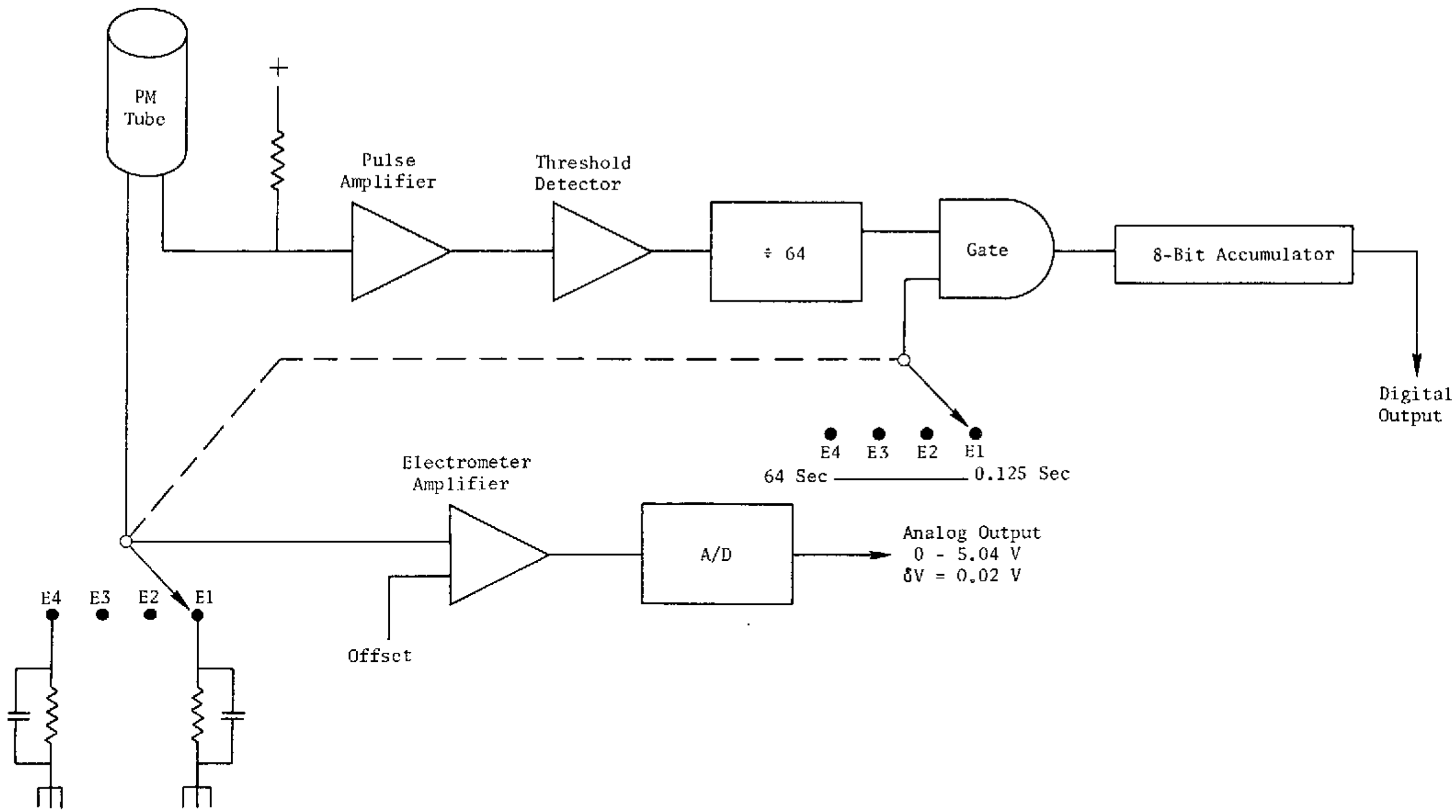

Figure 2.2-1. Electronic System for Stellar Photometers

Table 2.2-1

Circuit Parameters for Different Exposure/Gains

Exposure/ gain	Exposure Time (seconds)	Full-scale Current (amperes)	Rise Time (seconds)	Resistor (megohms)
E1	0.125	10^{-6}	0.03	5
E2	1	10^{-7}	0.25	50
E3	8	10^{-8}	1.9	500
E4	64	10^{-9}	15.0	5000

2.3 HISTORY OF KNOWN MALFUNCTIONS AFFECTING STELLAR PHOTOMETER DATA

Some examples of malfunctions which affect stellar photometer data are temporary failures of the digital counter on Stellar Photometer 1, misalignment of Stellar Photometer 3, a bit failure in the second half of data storage, and a startracker-guide star error which caused large spacecraft pointing errors. The ability to detect these and other problems has not been programmed into DROOP. Therefore, the user of WEP data must be able to recognize erroneous data caused by these malfunctions. To aid in evaluating data, the known malfunctions are presented in Table 2.3-1. The contents of Table 2.3-1 are the malfunctions, the photometers affected, clues to recognition of erroneous data, orbits believed affected, DROOP tapes believed affected, and remarks. Further information on some of the malfunctions can be found in Bendell (1972).

Changes in filter-photomultiplier response are considered elsewhere.

TABLE 2.3-1

Summary of Stellar Photometer Malfunctions

Malfunction	Stellar Photometer	Clue	Orbits	DROOP Tape(s)	Remarks*
Digital Counter	1	Digital counts always "1" or varying randomly	76- 84	001	
			2658-2664	132	
			2727-2757	141-142	
			2778-2789	142	
			3102-3127	151-152	
			3404-3426	171	
			3936-4035	191-201	
			4718	231	
			5103-5127	263	
			5882-5956	302-311	
			5958-6031	312-313	
			6285-6287	321	
			18464	1521	
Filter Wheel Skipping	2	Indication of filter changes within a frame (not a filter cycle frame); filter "0"	Increasing until 12455	Increasing until 921	
Filter Wheel Skipping	4	Indication of filter changes within a frame accompanied by variations in the data.	21128-end	1791-end	
Filter Wheel Sticking	2	No filter changes	12455-12493	921-922	1
			12502-12530	922	1
			12539-13831	922-1052	2
			13831-15431	1052-1221	1
			15431-end	1221-end	3

*See 'Remarks,' page 2.3-5.

TABLE 2.3-1 (continued)

Malfunction	Stellar Photometer	Clue	Orbits	DROOP Tape(s)	Remarks*
Misalignment	4	Raw digital counts much lower than expected from the signals measured by other instruments	0- 595	0001-0033	4
Misalignment	3	Measurements much fainter than expected from the signals measured by other instruments	595- 794	0033-0041	5
Misalignment	3	Rapid variations in data; measurements much fainter than expected from other photometers	4735-8970	231-581	6,7
Misalignment	4	Rapid variations in data; measurements much fainter than expected from other photometers	10848-12671	761-941	6
Star Tracker Guide Star 42 Pointing Error	1,2,3,4	Rapid variations in data; measurements much fainter than expected from other photometers	13732-13840 14796-14847 18624-18791	1042-1052 1152-1161 1532-1552	8
Bit Failure in Second Half of Data Storage	1,2,3,4	Stellar Photometer 4 analog measurements of 0.08 or 0.16	3418-end	171-end	9

*See 'Remarks,' page 2.3-5.

TABLE 2.3-1 (concluded)

Malfunction	Stellar Photometer	Clue	Orbits	DROOP Tape(s)	Remarks*
False Analog Saturation	1,2	Analog measurement starts at 5.04 volts and drops to low value while digital measurement remains constant	Anytime	Any	10
High-Voltage Power Supply Failure	1,2,3,4		21818-end	1813-1831	

*See 'Remarks,' page 2.3-5.

Remarks:

1. Stuck on FILTER 5 (2386 A).

2. Stuck on FILTER 1 (2035 A).

3. Stuck on FILTER 3 (DARK).

4. No stars were detected by Stellar 4 in this orbit interval.

5. Few WEP observations were obtained during this orbit interval because Celescope was being used during most of it.

6. See Section 4.8. Stellar 3, during most of the orbit interval 4210-8299, and Stellar 4, during the orbit interval 10848-12671, were misaligned by less than the radius of the field of view. Therefore, the detection or lack of detection of a star depended upon the size and direction of the pointing errors. Therefore, the user can expect to find both good and bad data from these instruments. The orbits listed here are where there may be problems.

7. A bad observation occurs at Orbit 4283. The next bad observation of which the authors are aware occurs in Orbit 4980. The orbit interval listed here allows for the possibility that a realignment of the star trackers at Orbit 4210 was the cause of the shift in relative alignment of the photometers.

8. Guide star 42 was λ Scorpii. The star tracker may have been guiding on the center of light of λ Scorpii and ν Scorpii. This error could shift the observatory pointing as much as 5 minutes of arc, depending upon other circumstances. For several reasons these intervals may contain both good and bad data.

9. This problem occurs only after 4096 words of data [22 Mode-'A' frames] are in data storage. The erroneous bit causes an error of +0.16 volt in the analog data of Stellar 1 and Stellar 4, and a possible error of +4 counts in the digital data for all four photometers.

10. DROOP is capable of handling this problem. It is mentioned here for completeness.

3. DESCRIPTION OF THE PHOTOMETER DATA

The following description refers to the results of the processing of OAO 2 data with the DROOP (data reduction of OAO photometry) software. This software, developed at the University of Wisconsin, allows for the computer reduction of large amounts of useful photometer data. The resulting data are available on magnetic tapes (as NSSDC data set 68-110A-02A) and also on microfilm (as NSSDC data set 68-110A-02B). The two data sets are almost identical; the microfilm version was generated by processing the magnetic tapes on a tape-to-microfilm printer. The only difference between the two data sets is that each roll of microfilm contains the output of two or more magnetic tapes, one concatenated behind the other. The following description applies to a dump of one tape only.

The reduced photometer data from the DROOP program are best viewed as belonging to one of three classes: 'overview' data, 'object' data, and 'frame' data. First, there are the overview data, derived from and applicable to an entire tape. These data include such items as the analog volts per digital overflow, spacecraft ephemeris, etc.

Secondly, there are the data summarizing observations of a particular object. Object data include a page summarizing all of the observations made of an object in question in a particular observing run (i.e., a photometer sequence executed in one interval of spacecraft night) and a page giving equations and plots for the dark current as a function of time during the observing run.

Finally, there are data from each individual observing frame. These frame data are not reduced if the observations were (a) not made in Mode A (i.e., not in the stellar photometer mode), (b) made during spacecraft day, or (c) made when the spacecraft was traversing the predicted South Atlantic Geomagnetic Anomaly. Since the various different telescope sets were not oriented rigorously in parallel to each other, offset problems negate the utility of the photometer data even when they were taken in Modes B or C.

During spacecraft day, reflected light posed too great a problem to allow good observations to be made.

The South Atlantic Geomagnetic Anomaly is a region where the Earth's magnetic field is relatively low at low altitudes. Because of this peculiar field intensity, geomagnetically trapped particles occurred in great numbers at the orbit of OAO 2. These particles caused an unacceptably high background noise in the photomultiplier tubes and thus degraded the data considerably.

Reduced frame data include various items of target information, spacecraft command information, raw analog and digital data, estimated number of digital overflows, crude plots of raw analog volts versus time and digital counts versus time for each of the six observations made during a frame, and the reduced analog and digital data with the dark subtracted and the result normalized to the mean (CAL - DK).

Note that many sets of object data are included on each tape while only one set of overview data is included. Each set of object data includes many sets of frame data. Subsequently, each class of data (i.e., overview, object, and frame data) will be examined in detail.

3.1 DESCRIPTION OF THE OVERVIEW DATA

This section describes the data that were generated by the DROOP program on the first pass through all of the raw data on a given tape (approximately 2 days of observations). DROOP software requires that two passes be made through a given raw data tape, the first pass being used to generate conversion factors and constants while the second pass uses these conversion factors and constants to reduce the raw data.

Some overview data (spacecraft orbital elements, volts/overflow, offsets, dark count transformations) are input to DROOP and are derived from external sources and programs. Other overview data, such as average CAL - DK and the dark curve fit for object data, are generated by DROOP in its first pass through the raw data tape.

Figure 3.1-1 shows the first page printed from a DROOP output tape. The first part of Figure 3.1-1 (table A) lists coefficients derived from a regression of measured analog voltages versus measured digital counts. The relation is in the form:

Analog voltage = offset + (digital counts) x (volts/overflow) ÷ 256   (3.1-1)

The factor of 256 is necessary because there were 256 counts accumulated for each accumulator overflow. In theory, a change in exposure/gain by one increment changes the volts/overflow by a factor of 1.25, since a change in gain changes the voltage scale by a factor of 10 and the accumulation time by a factor of eight. Thus, $V/O_{E2} = 1.25 \times V/O_{E1}$, or $V/O_{E2} = (V/O_{E3})/1.25$.

Section A of the table lists by columns: the instrument (ST1 is Stellar Photometer 1, SP1 is Spectrometer 1, etc.); the exposure time for which the data were derived (e.g., E1 = 0.125-sec accumulation time, analog full scale 10^{-6} amps; E2 = 1.0-sec accumulation time, analog full scale 10^{-7} amps; etc.); whether the data used included or excluded data taken in the South Atlantic Anomaly (heading ANOMALY); the type of data used (heading: TYPE; 'filter' is the normal type for Photometers ST1,ST2,ST3, and ST4); the number of points used in the regression (heading: NO OF POINTS): the derived analog volts per digital accumulator overflow in volts/overflow (heading: VOLTS/OVERFL); error in the volts per overflow (heading: ERROR); the voltage offset in volts (heading: OFFSET); the error in the offset (heading: ERROR); and finally, the week and the part of that week of OAO 2/WEP operation for which this table applies.

Note that in addition to the tabulated error in volts/overflow, the values given for that quantity may contain systematic errors because they represent the result of a linear least-squares fit applied to data that might include nonlinear effects because of the digital counter dead time. Moreover, the drift in the analog electronics was occasionally so rapid that no single value of offset and volts/overflow could be valid for an entire DROOP output tape.

```
    OUTPUT       0  0  0
              ANOM-          NO OF   VOLTS/
                ALY   TYPE  POINTS   OVERFL     ERROR      OFFSET     ERROR
    ST1 E1    EXCL   FILTER    61   1.13270    .00741     .10783    .01767   WEEK    , PART 1
    ST1 E2    EXCL   FILTER    14   1.33596    .01747     .10884    .01067   WEEK    , PART 1
    ST2 E1    EXCL   FILTER   365   1.06610    .01120     .04820    .01280   WEEK    , PART 1
    ST2 E2    EXCL   FILTER    45   1.65766    .05411    -.08416    .04751   WEEK    , PART 1
A   ST2 E3    EXCL   FILTER    12   2.69624    .01468    -.04474    .01059   WEEK    , PART 1
    ST3 E2    EXCL   FILTER   152    .09086    .00023     .01717    .00329   WEEK    , PART 1
    ST3 E3    EXCL   FILTER   113    .10444    .00039     .04870    .00430   WEEK    , PART 1
    ST3 E4    EXCL   FILTER    50    .12440    .00186     .03746    .00927   WEEK    , PART 1
    SP1 E3    EXCL            578    .07998    .00005    -.00003    .00119   WEEK    , PART 1
    SP1 E4    EXCL            234    .09972    .00017     .01636    .00203   WEEK    , PART 1
    SP2 E4    EXCL            109    .36076    .00236    -.03377    .01137   WEEK    , PART 1
    END FITS                                                                WEEK    , PART 1
B   OFFSETS         .12000   .00300  -.06000   .00200   .03481   .00356     WEEK  0, PART 1
    DKCOR          0.1775   -0.1550  0.00100  0.3800  -0.00225  0.4125      WEEK  0, PART 1
C
    DROOP   RUN ID =TC0082    11/02/73    21:31:15

    DROOP UPDATE NUMBER 17. COMPLETED DEC 12, 1972.
```


Figure 3.1-1. DROOP Output (Overview): First Page

At the bottom of the table, on line B, are listed the raw mean values of the offsets in the format: offset for ST1, error in offset for ST1; offset for ST2, error in offset for ST2; offset for ST3, error in offset for ST3 (offsets and errors in ST1, ST2, and ST3 are gain-independent), followed by dark count correlations. These correlations, appearing on line C, are used to transform dark data from ST2, ST3, and ST4 to the value of the dark counts for ST1. The data are given in pairs in the form of slope and intercept for Photometers ST2, ST3, and ST4, in the line labelled DKCOR. These values are to be used in the following formula:

$$\text{(Dark counts of ST(N) at E2)} = \text{(Slope (ST(N)) x ST1 dark Counts)} + \text{Intercept (ST(N))}. \qquad (3.1\text{-}2)$$

The inverse relations are used to put dark data on an "ST1" basis for a collective curve fit in the event an individual photometer has insufficient or missing dark data.

Following this page is a five-page description of DROOP (or notes on the automatic reduction of OAO photometry). This description should be read before proceeding further (see Figures 3.1-2a through 3.1-2e).

On the next page (see Figure 3.1-3) are given iterations of the mean offsets (line A) and a list of the calibration slide data (averaged over the entire tape) for each stellar photometer, for both analog and digital channels, at Exposure/gain 2 (table B). Also given are the uncertainties in the calibration data. Following that list is a table of corrections (table C) for errors made in estimating the number of overflows. These corrections were devised by normalizing 256 counts to Exposure/gain 2 and dividing by the (CAL - DK) counts for the interval involved. For a given detector, the factor relating this correction from one exposure/gain to the next is 0.125 (e.g., $corr_{E2} = 0.125 \times corr_{E1}$).

The next page (see Figure 3.1-4) gives a summary for the entire tape, including such items as the number of contacts (a contact is a memory dump to a ground station that generally occurs during the orbit following a set of observations), the number of frames found, the number and types of errors found, command statistics, and the number of targets observed.

The next summary (see Figure 3.1-5) lists the objects observed. Given for each object are (a) abbreviated name or HD number, (b) right ascension, (c) declination, (d) magnitude, (e) spectral type, (f) luminosity class, (g) peculiarity class, (h) visual magnitude, (i) B-V, and (j) U-B. Item (k) shows either the spacecraft pitch and yaw pointing from the object being observed, or the pointing offsets from a star near which a sky observation was made (if via use of a bore-sighted startracker in the latter case). The units of the pointing offsets

A DESCRIPTION OF DROOP (DATA REDUCTION OF OAO PHOTOMETRY)
NOTES ON THE AUTOMATIC REDUCTION OF OAO PHOTOMETRY

MANY FACTORS INFLUENCE THE QUALITY OF OAO PHOTOMETRIC DATA AND ITS AMENABILITY TO COMPUTERIZED REDUCTION. AMONG THESE ARE THE OBSERVING SEQUENCE ITSELF (I.E. THE PRESENCE AND TIMING OF FILTER, CALIBRATION AND DARK OBSERVATIONS), ITS EXECUTION RELATIVE TO THE INTERVAL OF SPACECRAFT NIGHT, EFFECTS OF THE SOUTH ATLANTIC ANOMALY AND THE SPECTRAL TYPE, BRIGHTNESS AND EVEN THE INTERSTELLAR REDDENING OF THE OBJECT UNDER STUDY.

THE SPACE ASTRONOMY LABORATORY COMPUTER PROGRAM DROOP (DATA REDUCTION OF OAO PHOTOMETRY) IS A COMPROMISE BETWEEN COMPLEXITY AND THE NUMBER OF OBSERVATIONS IT CAN BE EXPECTED TO PROCESS IN A SATISFACTORY FASHION. DROOP, TOGETHER WITH OTHER INITIALIZING PROGRAMS, IS DESIGNED TO ACCOMPLISH THE BASIC DATA PROCESSING NECESSARY FOR THE FURTHER ANALYSES OF PROGRAM OBJECTS. IN THIS CATEGORY ARE INCLUDED THE DETERMINATION OF THE CALIBRATION FACTOR FOR EACH PHOTOMETER, THE NUMBER OF OVERFLOWS, IF ANY, OF THE DIGITAL COUNTERS AND THE DARK CONTRIBUTION TO THE SIGNAL.

ALL OBSERVING SEQUENCES USED EXTENSIVELY IN THE OAO OBSERVING PROGRAM INCLUDE COMBINATIONS OF FILTERS AND GAINS SUCH THAT EACH FILTER IS USED MORE THAN ONCE AND AT VARIOUS GAINS. ANY ONE FILTER-GAIN COMBINATION IS EXECUTED SIX TIMES IN SUCCESSION AND COMPRISES ONE FRAME IN AN OBSERVING SEQUENCE. IF THE SIX LINES OF DATA PASS A NUMBER OF TESTS FOR CONSISTENCY, THEY ARE AVERAGED AND DARK IS SUBTRACTED. THIS QUANTITY, NORMALIZED TO THE PHOTOMETER'S RESPONSE TO THE CALIBRATION SLIDE, IS THE BASIC OBSERVATIONAL DATUM COMPUTED BY DROOP AND IN THE OUTPUT, IS LABELED 'DIG'. WRITING THIS AS FOLLOWS, DIG = (OBJECT-DARK)/(CAL-DARK), IT SHOULD BE NOTED THAT THE QUANTITY (CAL-DARK) IS AN AVERAGE TAKEN OVER THE ENTIRE DATA TAPE BEING PROCESSED, GENERALLY ONE-THIRD TO ONE-HALF OF A WEEK OF OAO OBSERVATIONS. THE OVERALL STABILITY OF THE PHOTOMETERS IS SUCH THAT THIS MEAN YIELDS HIGHER ACCURACY THAN INDIVIDUAL CALIBRATION MEASUREMENTS. THE QUANTITIES IN THE NUMERATOR ARE DERIVED ONLY FROM DATA COLLECTED DURING A SINGLE EPISODE OF SPACECRAFT NIGHT, THAT IS, ONE FILTER-CAL-DARK OBSERVING SEQUENCE.

THE PRINTOUT OF A DROOP-PROCESSED FRAME IS HEADED BY SEVERAL LINES OF INFORMATION WITH REGARD TO OBJECT IDENTIFICATION AND SPACECRAFT STATUS FOLLOWED BY THE RESULTS OF THE PROGRAM CALCULATIONS. THESE, INCLUDE THE QUANTITY 'DIG' FOR EACH OF THE FILTERS PLUS THE ESTIMATED ERROR, DARK COUNT, DATA QUALITY FLAGS, AND THE METHOD OF AVERAGING. A NUMBER OF OTHER HANDY PIECES OF KNOWLEDGE ARE ALSO LISTED INCLUDING ALL THE ORIGINAL RAW ANALOG AND DIGITAL DATA.

ALL OBSERVATIONS IN A SEQUENCE THROUGH A GIVEN FILTER ARE AVERAGED BY WEIGHTING THE INDIVIDUAL DATA POINTS BY THE INVERSE OF THEIR CALCULATED ERROR. THESE AVERAGES, TOGETHER WITH THE CALIBRATION DATA, ARE PRESENTED IN THE SUMMARY THAT APPEARS AT THE HEAD OF EACH SEQUENCE.

ALONG WITH THE DIGITAL RESULT FOR EACH FILTER, AN AUXILIARY QUANTITY IS COMPUTED WHICH PUTS THE CAL-NORMALIZED DATA ON A MAGNITUDE SCALE WITH COMPENSATION FOR THE RELATIVE SYSTEM SENSITIVITY. THIS QUANTITY IS 'OAO-MAG' AND IS DEFINED AS

-2.5 LOG(DIGITAL) - 2.5 LOG(DELTA),

WHERE 'DIGITAL' IS THE RESULT APPEARING ON THE PREVIOUS LINE IN THE SUMMARY PAGE AND 'LOG DELTA' IS THE SYSTEM RESPONSE RELATIVE TO ST1,F1, TABULATED BELOW.

LOG DELTA, SYSTEM RESPONSE RELATIVE TO S1F1

S1	F3	(4250A)	-0.680	S3	F2	(2460A)	+0.815
	F1	(3320A)	0.000		F1	(1910A)	1.644
	F4	(2990A)	+0.123		F5	(1680A)	2.466
S2	F2	(2950A)	0.043	S4	F1	(1550A)	2.114
	F5	(2390A)	0.461		F3	(1430A)	2.216
	F1	(2040A)	0.720		F4	(1330A)	2.696

BARRING MODIFICATIONS TO THE ABOVE TABLE, ONLY ONE FURTHER QUANTITY IS REQUIRED TO PUT THE ENTIRE PHOTOMETRIC SYSTEM ON AN ABSOLUTE SCALE, NAMELY, THE ABSOLUTE RESPONSE AT 3320A.

FOLLOWING THE SUMMARY PAGE IS A LISTING OF THE COEFFICIENTS OF THE DARK CURVE FIT AND A DARK DATA PLOT IN TERMS OF ST1, E2.

AS A STANDARD DATA REDUCTION ROUTINE, DROOP PERFORMS WELL IN PROCESSING COMPLETE OBSERVING SEQUENCES OF THE BRIGHTER STARS. WHEN REQUIRED TO REDUCE INCOMPLETE SEQUENCES (FOR EXAMPLE, WHEN FRAMES OF DARK DATA ARE LOST) OR DATA COLLECTED FROM MORE DIFFICULT OBJECTS (NEBULAE, GALAXIES OR FAINT STARS) THE RESULTS ARE LESS SATISFACTORY. NO ATTEMPT WAS MADE TO INCORPORATE INTO DROOP THE MULTITUDE OF COMPLEX DECISIONS AND APPROXIMATIONS THAT MIGHT BE MADE IN THE HAND REDUCTION OF DIFFICULT DATA.

OBSERVERS WHO WISH TO USE DROOP-PROCESSED DATA ALONE OR AS A PARTIAL FOUNDATION FOR FURTHER HAND REDUCTION SHOULD KEEP THE FOLLOWING COMMENTS IN MIND.

1. SKY BACKGROUND -- FOR MANY OBJECTS, THE SKY BACKGROUND IS IMPORTANT AND HAS BEEN OBSERVED FREQUENTLY.

Figure 3.1-2a. Description of DROOP Output, Page 1

DROOP TAKES NO SPECIAL NOTICE OF SUCH MEASUREMENTS AND, THUS, WHILE STILL REDUCING SKY DATA, MAKES NO SKY SUBTRACTION FROM THE OBJECT DATA.

2. INCOMPLETE PHOTOMETRY SEQUENCES -- AS OUTLINED BELOW, DARK DATA IS THOROUGHLY EXAMINED. A LEAST SQUARES FIT OF THE VARIATION OF DARK WITH TIME IS ATTEMPTED (UP TO THE SECOND POWER IN TIME). HOWEVER, IF LITTLE DARK DATA IS AVAILABLE FOR THE ORBIT IN QUESTION, THE OBSERVER MAY WISH TO USE A VALUE OTHER THAN THAT COMPUTED BY DROOP. IF NO DARK DATA IS AVAILABLE IN THAT INTERVAL, THEN DROOP SETS THE DARK EQUAL TO ZERO, THE RESULTS FOR ADJACENT ORBITS USUALLY PROVIDE A USEFUL ESTIMATE FOR A HAND REDUCTION. FILTER DATA IS, OF COURSE, ALSO SUBJECT TO SIMILAR OBSERVATIONAL FLAWS.

3. BIASED AVERAGE -- IN A SERIES OF MEASUREMENTS, ONE VALUE, SAY THE ONE OBTAINED AT THE LOWEST OF THREE GAINS, MAY DIFFER FROM THE OTHERS ENOUGH SO THAT, IN THE CASE OF A HAND REDUCTION, IT MIGHT HAVE BEEN REJECTED. DROOP MAKES NO SUCH DECISIONS. ALL VALUES FROM ALL FRAMES WHICH PASSED THEIR INDIVIDUAL INTERNAL-CONSISTENCY TESTS ARE USED IN COMPUTING THE ERROR-WEIGHTED AVERAGE MENTIONED PREVIOUSLY. THUS EACH FRAME OF AN OBSERVING SEQUENCE SHOULD BE EXAMINED AND ALL DATA FOR A GIVEN FILTER CHECKED FOR AGREEMENT. NATURALLY, IF ANY VALUES ARE THROWN OUT, A NEW DIGITAL AVERAGE MUST BE COMPUTED BY HAND. THIS PROBLEM CERTAINLY MAY ARISE FOR EVEN THE BRIGHTER VISUAL OBJECTS SINCE THEIR INTRINSIC ENERGY DISTRIBUTIONS AND THE INFLUENCE OF INTERSTELLAR REDDENING, INLUDING THE BUMP AT ABOUT 2200A, MAY YIELD A VERY LOW SIGNAL IN CERTAIN FILTERS. THE VERY BRIGHTEST STARS ALSO PRESENT DIFFICULTIES IN THE ESTIMATION OF THE NUMBER OF OVERFLOWS -- PARTICULARY IN THE CASE OF STELLAR 3.

NO MODIFICATIONS TO DROOP ARE ANTICIPATED AT THIS TIME. ANY CHANGES IN DROOP-PROCESSED DATA THAT ARE NOW CERTIFIED AS 'GOOD' WILL MORE THAN LIKELY ARISE FROM REFINEMENTS IN THE RELATIVE CALIBRATION, LOG DELTA, AND FROM THE ESTABLISHMENT OF THE ABSOLUTE FLUX SCALE.

DROOP IS A TWO PASS PROGRAM. ON PASS ONE A CURVE WHICH FITS DARK DATA TO TIME IS COMPUTED. THE CAL SLIDE DATA IS AVERAGED FOR THE WHOLE TAPE TO PRODUCE THE CALIBRATION CONSTANTS. ON PASS TWO ALL ANALOG AND DIGITAL DATA IS REDUCED AND PRINTED OUT IN A READABLE FASHION.

DROOP REDUCES ONLY THOSE FRAMES UNDER PHOTOMETRY CONTROL (MODE A AND MODE B COMMANDS) WHICH WERE TAKEN IN DARKNESS OUTSIDE THE SAA (SOUTH ATLANTIC ANOMALY). MODE A FRAMES IN WHICH THE FILTERS ARE CYCLED ARE NOT REDUCED BY DROOP. THE RAW DATA IS REPRODUCED IN THE STRIPPER FORMAT FOR ALL FRAMES NOT REDUCED, NAMELY THOSE UNDER SCANNER CONTROL (MODE C COMMANDS), THOSE TAKEN IN DAYLIGHT, THOSE IN THE SAA, THOSE WHICH ARE MODE A DO-CYCLE'S, AND THOSE FOR WHICH THE STAR IS OCCULTED BY THE EARTH.

I. PASS ONE

A. DARK COMPUTATION

RAW DATA IS READ FOR ONE ORBIT. DATA FROM SEVERAL STARS MAY BE INCLUDED. MODE C AND MODE A DO-CYCLE FRAMES ARE NOT USED. OBSERVATIONS MADE IN THE SAA, IN DAYLIGHT AND WHEN THE STAR IS SET ARE USED WHEN ALL FOUR PHOTOMETERS HAVE DARK SLIDES AND THESE FRAMES BRACKET A NORMAL PHOTOMETRY SEQUENCE. WHEN THE ANALOG OF A DARK FILTER IS SATURATED, DARKS ARE NOT USED FOR THAT PHOTOMETER. A CURVE OF DARK DATA VS TIME IS COMPUTED. THERE ARE TWO METHODS FOR COMPUTING THIS CURVE.

1. INDIVIDUAL FITS

IF THE FIRST AND LAST FRAMES HAVE DARK SLIDES ON ALL FOUR PHOTOMETERS, INDIVIDUAL CURVE FITS FOR EACH PHOTOMETER ARE MADE. A SECOND-ORDER LEAST SQUARES FIT (SUBROUTINE SECLSQ) IS ATTEMPTED. IF THE ERROR IS TOO LARGE (GREATER THAN DISP1) FOR ANY ONE PHOTOMETER, THAT INSTRUMENT (AND THAT INSTRUMENT ALONE) IS GIVEN A COLLECTIVE CURVE FIT, AS FOLLOWS.

2. COLLECTIVE FITS

FOR A COLLECTIVE CURVE FIT, ALL DARK DATA (EXCEPT ST2,E1, ST3,E1,E2,E3, AND ST4,ALL GAINS) IS CONVERTED TO PHOTOMETER 1 USING TRANSFORMATION EQUATIONS WHICH ARE COMPUTED SEPARATELY FOR EACH DATA TAPE. IN THE EVENT THAT THESE TRANSFORMATIONS ARE NOT SUPPLIED TO DROOP, THE FOLLOWING DEFAULT VALUES ARE USED. THESE DEFAULT VALUES ARE BASED ON EARLY DATA.

ST2= .16 ST1 - .56
ST3= .0112 ST1 + .7908
ST4= .0032 ST1 + .7988

A SECOND-ORDER LEAST SQUARES FIT IS ATTEMPTED. WHEN THE ERROR IS TOO LARGE A FIRST-ORDER LEAST SQUARES FIT (SUBROUTINE LSTSQR) IS ATTEMPTED. WHEN THIS ERROR IS ALSO TOO LARGE, THE DATA IS AVERAGED, INDIVIDUALLY FOR EACH PHOTOMETER. IN THIS CASE THE DARK VS. TIME CURVE BECOMES A STRAIGHT LINE. WHERE DATA FOR ONE INSTRUMENT IS MISSING, THE TRANSFORMATION IS USED TO FILL IT IN. WHERE NO DARK DATA FOR ANY OF THE PHOTOMETERS IS AVAILABLE, THE DARK VALUE IS SET TO 0.0.

B. CALIBRATION CONSTANT

Figure 3.1-2b. Description of DROOP Output, Page 2

CAL SLIDE DATA IS AVERAGED IN THE NORMAL WAY (DESCRIBED UNDER ANALOG AND DIGITAL DATA AVERAGING). THE AVERAGES ARE STORED IN AN ARRAY AND A BINS AVERAGE IS TAKEN WHEN ALL DATA HAS BEEN COLLECTED. A ROOT MEAN SQUARE ERROR (FUNCTION RMS) IS COMPUTED AND USED AS THE CALIBRATION ERROR. THE CAL DATA IS NORMALIZED TO LAUNCH DATE TO COMPENSATE FOR THE DECAY OF STRONTIUM-90. WHEN NO CAL DATA IS PRESENT ON A DATA TAPE, THE FOLLOWING VALUES ARE USED. DIGITALS, ST1 165.0, ST2 68.0, ST3 252.0, ST4 143.0 ANALOG CALS ARE COMPUTED FROM THESE DIGITALS USING THE ANALOG-DIGITAL RELATIONSHIP.

II. PASS TWO

THE DATA TAPE IS NOW REWOUND. THE DARK AND CAL VALUES JUST COMPUTED ARE USED IN THE NEXT PHASE OF THE PROGRAM.

A. READING THE DATA TAPE

RAW DATA IS READ FOR ONE ORBIT OR ONE TARGET (WHICH EVER IS SMALLER). CERTAIN FRAMES ARE OMITTED AS PREVIOUSLY EXPLAINED.

B. SATURATION ESTIMATION

ALL ANALOG DATA IS CHECKED FOR SATURATION. IF A FRAME HAS ANY SATURATED READINGS, AN ESTIMATE OF THE TRUE ANALOG VOLTAGE IS MADE (SUBROUTINE SAT1). IF NON-SATURATED DATA FOR THAT SAME FILTER AT A LOWER GAIN EXISTS IN THAT ORBIT, THE ESTIMATE IS MADE BY SIMPLE GAIN CONVERSION. THE AVERAGE IS THEN FLAGGED 'EST FROM FRAME N'. IF NO UNSATURATED DATA IS PRESENT, THE ESTIMATE IS MADE BY USING STELLAR MODELS (SUBROUTINE MODEL). INTERSTELLAR REDDENING AND CHANGES IN THE SENSITIVITY OF THE INSTRUMENTS ARE TAKEN INTO CONSIDERATION WHEN COMPUTING A VALUE FROM THESE MODELS. NO ESTIMATE IS MADE FOR SATURATED DARK OR CAL SLIDE.

C. ANALOG DATA REDUCTION

AFTER DARK AND OFFSET HAVE BEEN SUBTRACTED FROM THE ANALOG READING, THE FRAME IS AVERAGED BY THE 'BINS' METHOD (SUBROUTINE ANABIN). IN THIS METHOD OF AVERAGING, THE DATA IS POPPED INTO BINS AND THE AVERAGE IS MADE BY INCLUDING ONLY THOSE VALUES WHICH FALL IN THE TEN BINS SURROUNDING THE MOST POPULOUS BIN. THE BIN SIZE IS DETERMINED BY TAKING A PERCENTAGE OF THE MEAN OF THE DATA OR 0.04 VOLTS, WHICHEVER IS LARGER. THIS PERCENTAGE IS INPUT ON THE 'BIN SIZE' CARD, OR IT HAS A DEFAULT VALUE OF 2 PERCENT.

THERE ARE THREE CASES IN DETERMINING THE MOST POPULOUS BIN.

1. THERE IS ONLY ONE MOST POPULOUS BIN
2. THERE ARE TWO BINS OF EQUAL SIZE.
   A. IF THESE TWO BINS ARE MORE THAN THREE BINS APART, THE MOST POPULOUS BIN IS DEFINED AS THE SMALLER OF THE TWO.
   B. IF THESE TWO BINS ARE LESS THAN 3 BINS APART, DEFINE THE MOST POPULOUS BIN AS THE AVERAGE OF THE TWO.
3. THERE ARE N BINS OF EQUAL SIZE.
   A. IF THE LARGEST AND THE SMALLEST BINS ARE MORE THAN TEN BINS APART, NO AVERAGE IS TAKEN.
   B. IF NOT 'A' ABOVE, THE MOST POPULOUS BIN IS DEFINED AS THE MIDDLE ONE.

THE FINAL AVERAGE IS FORMED BY USING ONLY THOSE VALUES WHICH FALL IN THE TEN BINS SURROUNDING THE MOST POPULOUS BIN.

IF A BINS AVERAGE IS MADE, THE AVERAGE IS FLAGGED 'SMALL BINS'. WHEN NO AVERAGE IS POSSIBLE, IT IS TRIED ONCE AGAIN DOUBLING THE BIN SIZE. IF THIS WORKS, THE AVERAGE IS FLAGGED 'LARGE BINS'. NO AVERAGE IS MADE WHEN THE LARGE BINS AVERAGING FAILS, AND THE DATA IS FLAGGED 'REJECTED'.

STELLAR 4 ANALOG IS ESTIMATED BY THE MODELS (SUBROUTINE MODEL). THE DATA IS FLAGGED 'EST FROM MODELS'. IF THIS ESTIMATE IS IMPROVED (DESCRIBED IN SECTION D, BELOW), THE DATA IS FLAGGED 'IMPROVED EST'. THE RATIO COMPUTED FOR STELLAR 4 IS FROM STELLAR 3 DATA, AND IT IS ASSUMED THAT THE RATIO DOES NOT VARY ACCORDING TO WAVELENGTH.

THE FILTER NUMBER, GAIN AND APERTURE ARE ALSO AVERAGED BY THE BINS METHOD (SUBROUTINE ARAGE). HOWEVER IN THIS CASE, THE AVERAGE IS SET TO THE SMALLEST MOST-POPULOUS BIN.

D. IMPROVED ESTIMATE OF SATURATED ANALOG DATA

AN IMPROVED ESTIMATE OF ALL SATURATED ANALOG DATA IS ATTEMPTED (SUBROUTINE SAT2) AND FOR STELLAR 4 ANALOG. A CORRECTION TERM FOR THE ESTIMATE IS COMPUTED IN THE FOLLOWING MANNER. A GOOD ANALOG AVERAGE FOR THE SAME PHOTOMETER BUT WITH A DIFFERENT FILTER IS CHOSEN, AND AN ESTIMATE FOR THAT FILTER IS MADE FROM THE MODELS. THE FOLLOWING RATIO IS COMPUTED, MODEL/AVERAGE. THE ESTIMATE OF THE SATURATED DATA IS THEN MULTIPLIED BY THIS RATIO. THE DATA IS FLAGGED 'IMPROVED EST'. THE NUMBER FOLLOWING 'IMPROVED EST' IS THE FRAME NUMBER FROM WHICH THIS RATIO WAS MADE. IF NO SUCH RATIO CAN BE COMPUTED, THE AVERAGE IS FLAGGED 'EST FROM MODELS'.

E. DIGITAL DATA REDUCTION

Figure 3.1-2c. Description of DROOP Output, Page 3

THE NUMBER OF DIGITAL OVERFLOWS IS COMPUTED USING THE RESULTS OF CURT HEACOX'S PROGRAM ADPLOT, WHICH COMPUTES THE NUMBER OF ANALOG VOLTS PER DIGITAL OVERFLOW. STELLAR 4 IS A SPECIAL CASE SINCE NO ANALOG VOLTAGE IS AVAILABLE. THE ADPLOT DECK IS REQUIRED INPUT TO DROOP. THE NUMBER OF OVERFLOWS IS JUDGED TO BE 'CERTAIN' OR 'UNCERTAIN'. THE OVERFLOWS ARE CERTAIN IF THE DIFFERENCE BETWEEN THE CORRECTED DIGITAL AND THE DIGITIZED-ANALOG IS LESS THAN 128 MINUS THE DIGITAL ERROR. IT IS UNCERTAIN IF THE FORMER IS NOT TRUE OR IF THE DIGITAL ERROR IS GREATER THAN 128.

IF ONE FRAME HAS SOME 'CERTAIN' AND SOME 'UNCERTAIN' DATA, THE UNCERTAIN DATA ARE CORRECTED TO CORRESPOND TO THE CERTAIN DATA. THE DATA WHICH WERE CORRECTED ARE FLAGGED 'A' OR 'C' AS IS EXPLAINED UNDER DATA FLAGGING. THE AVERAGE OF A FRAME IN WHICH ALL DIGITAL OVERFLOWS ARE UNCERTAIN IS FLAGGED 'BAD'.

THE DARK IS SUBTRACTED FROM THE DIGITAL AND IT IS THEN AVERAGED VIA THE BINS METHOD AS DESCRIBED FOR THE ANALOG DATA (SUBROUTINES DRIFTD AND DIGBIN). THE BIN SIZE IS 2 COUNTS OR 2 PERCENT, WHICHEVER IS LARGER.

SINCE THE DATA IS MEASURED IN QUANTS, THERE IS AN INHERENT ERROR OF ONE-HALF COUNT. THIS HALF COUNT IS SUBTRACTED FROM THE DIGITAL AVERAGE.

THE FILTER 'BIAS' IS THEN SUBTRACTED OUT. THIS BIAS REPRESENTS THE NUMBER OF COUNTS REGISTERED BY THE PHOTO TUBE ABOVE THE DARK CURRENT, I.E., WHEN THE SUNSHADE IS CLOSED.

ST3	F1	+0.098	(+6.3 CTS AT E4)
	F2	+0.023	(+1.5 CTS AT E4)
	F5	-0.437	(-28 CTS AT E4)
ST4	F1	-0.147	(-9.4 CTS AT E4)
	F3	-0.153	(-9.8 CTS AT E4)
	F4	-0.016	(-1.0 CTS AT E4)

BECAUSE OF THE RAPID OVERFLOW RATE ON STELLAR 3, A SPECIAL ROUTINE (STUR) WAS WRITTEN TO HANDLE ITS OVERFLOW COMPUTATION. THERE ARE THREE OPTIONS. 1) WHEN ANALOGS FOR ALL OBSERVATIONS ARE ZERO, USE THE LOWEST GAIN DIGITAL TO PREDICT THE HIGHER GAINS. 2) WHEN THE SAME OBSERVATIONS HAVE SOME ZERO ANALOGS USE THE NORMAL METHOD ON THE ONES WITH NON-ZERO ANALOGS AND USE THESE TO PREDICT THE DIGITALS ON THE OTHERS. 3) WHEN THERE ARE NO OBSERVATIONS WITH ALL ZERO ANALOGS, USE THE NORMAL METHOD (SUBROUTINE DOVER).

THE DIGITAL OF STELLAR PHOTOMETER 4 IS A SPECIAL CASE BECAUSE NO ANALOG VOLTAGE IS AVAILABLE. THE NUMBER OF DIGITAL OVERFLOWS IS ESTIMATED IN THE FOLLOWING MANNER. FILTER 1 OF STELLAR 4 (1550 ANG) CAN BE ESTIMATED FROM FILTER 5 OF STELLAR 3 (1680 ANG). THE NUMBERS OF OVERFLOWS OF THE OTHER TWO FILTERS ARE ESTIMATED FROM THE MODELS. AFTER THIS IS COMPLETED, ELABORATE CHECKING IS DONE TO INSURE THAT THE CORRECT NUMBER OF OVERFLOWS HAS BEEN MADE. USING THE GAIN CONVERSION, IDENTICAL FILTER OBSERVATIONS AT DIFFERENT GAINS ARE CHECKED FOR CONSISTANCY.

F. FLAGGING OF DATA

EACH DATA POINT IS INDIVIDUALLY FLAGGED TO SHOW DATA QUALITY AND METHOD OF AVERAGING. THE LIST OF THESE FLAGS APPEARS ON THE OUTPUT SHEETS IN THE COLUMN HEADED 'FLAGS'

1. ANALOG FLAGS
   - 0 NO SATURATION
   - S SATURATION
   - W WRONG FILTER
   - B AVERAGED IN BINS
   - X 'W' AND SATURATION

2. DIGITAL FLAGS
   - 0 DATA PRESENT AND OVERFLOWS ACCURATE
   - U ESTIMATE OF OVERFLOWS NOT ACCURATE
   - A UNCERTAINTY OF OVERFLOWS WAS REMOVED
   - B '0' DATA AVERAGED IN BINS
   - C 'A' DATA AVERAGED IN BINS
   - D 'U' DATA AVERAGED IN BINS

3. REASONS DATA WAS NOT REDUCED (THIS FLAG APPEARS IN THE COLUMN LABELED 'DATA AVERAGING'.)
   - A FAILED ARITHMETIC AVERAGE
   - B ERRORS IN FILTER, GAIN, APERTURE OR MODE STATUS
   - C LARGE SCATTER IN DATA
   - D ANALOG DATA IS ZERO OR LESS THAN OFFSET OR STATUS ERRORS
   - E STELLAR 4 ANALOG IS NOT PREDICTABLE (DARK OR CAL SLIDE)
   - F MORE THAN TWO MOST POPULOUS BINS WITH LARGE SCATTER IN DATA
   - G NO DATA PUT INTO BINS (IMPLIES LARGE SCATTER)
   - H SECOND HALF OF STORAGE IS BAD
   - I ESTIMATION OF SATURATED DATA WAS LESS THAN 5.04 VOLTS

G. WEIGHTS

EACH AVERAGE IS GIVEN A WEIGHT WHICH GIVES AN ESTIMATE OF THE QUALITY OF THE AVERAGE. IN THE FOLLOWING EXAMPLES, N IS THE NUMBER OF POINTS INCLUDED IN THE AVERAGE.

Figure 3.1-2d. Description of DROOP Output, Page 4

SMALL BINS. WT = N
LARGE BINS. WT = N/2
MODELS ESTIMATE. WT = 0
ARITHMETIC. WT = 1
REJECTED. WT = 0

H. CALIBRATION CORRECTION

THE ANALOG AVERAGE, DIGITAL AVERAGE, AND THE DIGITIZED-ANALOG ARE THEN DIVIDED BY THE CALIBRATION CONSTANTS COMPUTED IN PASS ONE. THE ERROR IS COMPUTED IN THE FOLLOWING WAY.
ANALOG ERROR = SQRT ((ANALOG * CAL ERROR)**2 +
AVE ERROR**2) / ANALOG CAL
WHERE AVE ERROR IS THE LARGER OF RMS AND RME.
RME= 0.125 * SQRT(AVE/(N*(N-1))), RMS= ROOT MEAN SQUARE.
DIGITAL ERROR IS COMPUTED IN THE SAME WAY.

I. PRINTOUT

1. SUMMARY PAGE

THE SUMMARY PAGE CONTAINS ALL THE MEANINGFUL DATA FOR A STAR EXCEPT THE SCANS. IT INCLUDES A COPY OF THE STAR CARD, THE SUB-SATELLITE POINT AND POINTING OF THE SPACECRAFT, AND THE CALIBRATION CONSTANTS USED. THIS IS FOLLOWED BY A LIST OF AVERAGE READINGS FOR EACH PHOTOMETER AND EACH FILTER REDUCED TO GAIN 2, WEIGHTED BY THE ERROR. THE AVERAGE IS THE SUM OF (AVE DATA)/ERROR DIVIDED BY THE SUM OF (1/ERROR). IF THE NUMBERS WHICH GO INTO THE AVERAGE DIFFER BY MORE THAN 20 PERCENT, THE DATA IS FLAGGED WITH A '*'. IF THEY DIFFER BY MORE THAN 50 PERCENT, THE DATA IS FLAGGED WITH A '$'.

2. DARK CURVE FIT PAGE

INCLUDED ON THIS PAGE IS THE MODELS ESTIMATION OF ANALOG VOLTS FOR THAT STAR. FOLLOWING THAT ARE THE FOUR EQUATIONS FOR COMPUTING DARK CURRENT, WHERE T IS THE TIME FROM THE FIRST FRAME IN THE GROUP. THE RESULT IS IN DIGITAL COUNTS AT GAIN 2.

THERE IS ALSO A PRINTER PLOT SHOWING THE ACTUAL CURVES FOR EACH PHOTOMETER. THESE CURVES HAVE BEEN CONVERTED TO GAIN 2 AND TO STELLAR 1 USING THE CONVERSION FORMULAE. THE POINTS USED IN DETERMING THESE CURVES CONVERTED TO STELLAR 1 AT GAIN 2 ARE ALSO PLOTTED.

3. THE DATA

THE DATA IS PRINTED OUT FRAME BY FRAME, ONE FRAME PER PAGE, IN A FASHION SIMILAR TO STRIPPER OUTPUT. THE DATA AVERAGES, WEIGHTS, FLAGS, AND QUALITIES OF AVERAGING ARE LISTED FOR EACH PHOTOMETER. THE RAW DATA IS LISTED ALONG WITH A PRINTER-PLOT OF THE RAW DATA AS A VISUAL AID IN WATCHING THE TREND OF THE DATA. ON THE RIGHT HAND SIDE OF THE PAGE THERE IS A LISTING OF MAXIMUM ANALOG VOLTAGE FOR EACH LINE OF DATA. THE PURPOSE OF THIS IS TO SEE IF HEAVY SATURATION ON ONE PHOTOMETER WILL AFFECT THE NORMAL VOLTAGES ON THE OTHER INSTRUMENTS. THERE IS A LIST OF GAINS AND FILTERS FOR EACH LINE AND A LIST OF DIGITAL OVERFLOWS FOR EACH DATA POINT.

4. TAPE ORGANIZATION

THE DATA IS ORGANIZED IN FILES ON THE DATA TAPE. THE FRAMES FOR EACH STAR ARE ON A SEPARATE FILE. THERE IS ONE EXTRA FILE AT THE BEGINNING WHICH CONTAINS STRIPPER SUMMARIES. THIS IS FOLLOWED BY THE SERIES OF STAR FILES. AT THE END OF THE DATA, THERE IS A DOUBLE END OF FILE, AFTER WHICH COMES ONE FILE CONTAINING STRIPPER SUMMARIES, ANOTHER DOUBLE END OF FILE FOLLOWED BY ONE FILE CONTAINING ALL THE DROOP SUMMARIES. THE TAPE ENDS WITH A TRIPLE END OF FILE.

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Figure 3.1-2e. Description of DROOP Output, Page 5

```
(A) OFFSETS USED IN THIS PROGRAM ARE     ST1=  .12000     ST2=  .06000     ST3=  .03401     ST4=  .00000

    CALIBRATION READINGS CALCULATED FOR THIS TAPE (A STRAIGHT AVERAGE OF ALL CAL DATA AVAILABLE IS USED)
    THE HALF LIFE OF STRONTIUM-90 OF 25 YEARS HAS BEEN COMPENSATED FOR BY NORMALIZING THE CAL TO LAUNCH DATE.
(B) ST 1        ANALOG     .94 +OR-   .017 VOLTS                          DIGITAL  168.99 +OR-  2.471 COUNTS
    ST 2        ANALOG     .34 +OR-   .007 VOLTS                          DIGITAL   38.74 +OR-   .825 COUNTS
    ST 3        ANALOG     .17 +OR-   .002 VOLTS                          DIGITAL  240.71 +OR-  1.680 COUNTS
    ST 4        ANALOG    1.00 +OR-   .000 VOLTS                          DIGITAL  137.98 +OR-   .769 COUNTS

    THE NUMBER OF OVERFLOWS OF THE DIGITAL COUNTER IS EXTREMELY DIFFICULT TO PREDICT.  THE ADPLOT DECK,
    PRINTED OUT IN THE BEGINNING OF THE DROOP RUN, IS USED TO DETERMINE THE NUMBER OF OVERFLOWS.  THE NUMBER
    COMPUTED IS NOT ALWAYS CORRECT.  THE EXPERIMENTER MAY ADD OR SUBTRACT THE FOLLOWING NUMBERS TO (OR FROM)
    THE DIGITAL RESULT IN THE FOLLOWING PRINTOUT TO RAISE OR LOWER THE NUMBER OF OVERFLOWS.

                          E1          E2          E3          E4

          STELLAR 1     .121+02     .151+01     .189+00     .237-01

          STELLAR 2     .529+02     .661+01     .826+00     .103+00
(C)
          STELLAR 3     .851+01     .106+01     .133+00     .166-01

          STELLAR 4     .148+02     .186+01     .232+00     .290-01
```

Figure 3.1-3. DROOP Output (Overview): Calibration Data

```
************************************************ SUMMARY FOR OAO   1 ************************************************
 18 CONTACTS FOUND. 188 WEP FRAMES FOUND.  ERRORS:    0 MODE,   2 STRUCTURE,   1 DIGITAL SEQUENCE,   2 FRAME LENGTH.
235 WEP COMMANDS FOUND.  ERRORS:  58 MISSING COMMANDS,   0 ERRONEOUS COMMANDS.
 13 TARGETS OBSERVED.
***********************************************************************************************************************
```

Figure 3.1-4. DROOP Output (Overview): Tape Summary

STAR OBSERVATION SUMMARY FOR OAO 1

(A) NAME	(B) RA		(C) DEC		(D) MAG	(E) SP	(F) LC	(G) PEC	(H) MV	(I) B-V	(J) U-B	(K) COMMENTS				(L) CONTACT		(M) TIME OF FIRST OBS		(N) A	(O) B	(P) C	(Q) AN	(R) LT
BET CAR	9	12.69	-69	30.4	1.6	A1	IV	S	1.68	0.00	0.02	P=	0	Y=	0	57	R	12/11/68	06:19:34	6	1	11	17	18
IOT CAR	9	15.76	-59	3.5	2.2	F0	I		2.25	0.18	0.11	P=	0	Y=	0	63	S	12/11/68	17:46:24	10	2	3	3	11
91465	10	30.24	-61	25.4	3.3	B5	V	E	3.31	-0.10	-0.71	P=	0	Y=	0	66	S	12/11/68	22:34:31	10	2	3	5	10
I CAR	9	43.89	-62	16.8	3.4	G2			3.40	1.20		P=	0	Y=	0	70	R	12/12/68	03:40:11	10	2	0	0	6
BET CAR	9	12.69	-69	30.4	1.7	A1	IV	S	1.68	0.00	0.02	P=	0	Y=	0	70	R	12/12/68	05:00:56	11	2	0	0	9
GAM VEL	8	8.00	-47	12.1	1.8	C7			1.82	-0.26	-0.93	P=	0	Y=	0	71	R	12/12/68	06:17:45	1	0	8	3	7
BET CAR	9	12.69	-69	30.4	1.7	A1	IV	S	1.68	0.00	0.02	P=	0	Y=	0	76	S	12/12/68	12:59:38	6	1	1	2	6
IOT CAR	9	15.76	-59	3.5	2.2	F0	I		2.25	0.18	0.11	P=	0	Y=	0	76	S	12/12/68	13:52:35	6	1	0	0	3
83183	9	33.00	-59	0.3	4.1	B5	II		4.08	0.01	-0.56	P=	0	Y=	0	76	S	12/12/68	14:36:22	10	2	3	6	8
88206	10	7.04	-51	33.7	4.9	B2	V		4.85	-0.13	-0.71	P=	0	Y=	0	78	S	12/12/68	18:38:36	8	2	0	1	5
91465	10	30.24	-61	25.4	3.3	B5	V	E	3.31	-0.10	-0.71	P=	0	Y=	0	80	S	12/12/68	20:20:34	17	3	3	3	15
OMG CAR	10	12.57	-69	46.9	3.3	B7	IV		3.31	-0.08	-0.32	P=	0	Y=	0	84	R	12/13/68	01:45:38	12	3	0	0	14
BET CAR	9	12.69	-69	30.4	1.7	A1	IV	S	1.68	0.00	0.02	P=	0	Y=	0	84	R	12/13/68	03:01:24	12	2	14	0	19

Figure 3.1-5. DROOP Output (Overview): Summary of Objects Observed

(pitch and yaw) are in arc-minutes if initials P and Y are used. If the initials PT and YT are used (signifying usage of the bore-sighted star tracker), the units are 15 arc-seconds for the first 60 along each axis; additional units represent 1 arc-minute increments. Furthermore, positive units of PT or YT correspond to negative pointing offsets along that axis. Thus, for example, YT= 85 stands for a total offset of 40 arc-minutes in the negative yaw direction. [See Section 4.8 for a discussion of the relationship between the observatory coordinate system and the celestial coordinate system.]

Also listed are (l) number and initial of the ground station to which the data were transmitted from the satellite, (m) date and time of the first observation, (n,o,p) number of frames in each mode, (q) number of frames observed in the South Atlantic Geomagnetic Anomaly (heading: AN), and (r) number of frames observed in spacecraft daylight (heading: LT).

This is followed by a frame summary (see Figure 3.1-6). This frame summary lists, for each frame on the tape, (a) contact number and initial of the ground station, (b) frame number, (c) spacecraft clock setting (heading: SET), (d) date and time the observing sequence of the data in the frame was started, and, in three columns (e, f, and g), the mode (designated A, B, or C), day/night status of the spacecraft (designated D or N), and whether the spacecraft was in the South Atlantic Geomagnetic Anomaly (designated A or blank). The star summary and the frame summary are both repeated at the end of the main body of output, along with all 'object' data summaries.

The next page (see Figure 3.1-7) lists spacecraft ephemeris elements for this tape: a time correlation between GMT and the spacecraft clock, the semi-major axis, inclination, mean anomaly, position of perigee, right ascension of the ascending node, rate of change of the right ascension of the ascending node, day and minute of the epoch, calculated period, and Julian date of epoch.

```
************************************ FRAME SUMMARY FOR OAO   1 ************************************
   (A)    (B)  (C)              (D)        (E)(F)(G)
CONTACT FR  SET            GMT
   57 R   1 1616 12/11/68 06:19:34 CD

   58 R   1 2442 12/11/68 08:05:28 CDA
   58 R   2 2574 12/11/68 08:29:04 CDA
   58 R   3 2631 12/11/68 08:36:40 CDA

   59 R   1 3273 12/11/68 09:52:42 CDA

   60 R   1 4113 12/11/68 11:37:33 CDA
   60 R   2 4225 12/11/68 11:56:57 CDA
   60 R   3 4315 12/11/68 12:11:38 ADA

   62 S   1 4743 12/11/68 13:24:31 CDA
   62 S   2 5151 12/11/68 13:59:39 CDA
   62 S   3 5634 12/11/68 15:20:08 CDA

   63 S   1 6433 12/11/68 17:00:32 CDA
   63 S   2 6505 12/11/68 17:11:32 ADA
   63 S   3 6536 12/11/68 17:18:05 ADA
   63 S   4 6543 12/11/68 17:19:24 ADA
   63 S   5 6574 12/11/68 17:25:57 ADA
   63 S   6 6601 12/11/68 17:27:16 ADA
   63 S   7 6632 12/11/68 17:33:49 BDA
   63 S   8 6712 12/11/68 17:46:24 AN
   63 S   9 6743 12/11/68 17:52:57 AN
   63 S  10 6750 12/11/68 17:54:16 AN
   63 S  11 7001 12/11/68 18:00:49 AN
   63 S  12 7006 12/11/68 18:02:08 AD
   63 S  13 7037 12/11/68 18:08:41 BD
   63 S  14 7044 12/11/68 18:10:00 CD

   66 S   1 7736 12/11/68 20:05:53 CDA
   66 S   2 0254 12/11/68 20:59:53 CDA
   66 S   3 0572 12/11/68 21:53:53 AD
   66 S   4 0623 12/11/68 22:00:26 AD
   66 S   5 0630 12/11/68 22:01:45 AD
   66 S   6 0661 12/11/68 22:08:18 AD
   66 S   7 0666 12/11/68 22:09:37 AD
   66 S   8 0717 12/11/68 22:16:10 BDA
   66 S   9 1025 12/11/68 22:34:31 ADA
   66 S  10 1056 12/11/68 22:41:04 ANA
   66 S  11 1063 12/11/68 22:42:23 ANA
   66 S  12 1114 12/11/68 22:48:56 AN
   66 S  13 1121 12/11/68 22:50:15 AN
   66 S  14 1152 12/11/68 22:56:48 BN
```

```
   (A)    (B)
CONTACT FR  SET            GMT
   66 S  15 1157 12/11/68 22:58:07 CDA

   70 R   1 2042 12/12/68 00:52:09 CD
   70 R   2 2360 12/12/68 01:46:09 CDA
   70 R   3 2676 12/12/68 02:40:09 AD
   70 R   4 2727 12/12/68 02:46:42 AD
   70 R   5 2734 12/12/68 02:48:01 AD
   70 R   6 2765 12/12/68 02:54:34 AD
   70 R   7 2772 12/12/68 02:55:53 AD
   70 R   8 3023 12/12/68 03:02:26 BD
   70 R   9 3243 12/12/68 03:40:11 AN
   70 R  10 3274 12/12/68 03:46:44 AN
   70 R  11 3301 12/12/68 03:48:03 AN
   70 R  12 3332 12/12/68 03:54:36 AN
   70 R  13 3337 12/12/68 03:55:55 AN
   70 R  14 3370 12/12/68 04:02:28 BN
   70 R  15 3442 12/12/68 04:13:29 AD
   70 R  16 3473 12/12/68 04:20:02 AD
   70 R  17 3500 12/12/68 04:21:21 AD
   70 R  18 3531 12/12/68 04:27:54 AD
   70 R  19 3536 12/12/68 04:29:13 AD
   70 R  20 3567 12/12/68 04:35:46 BD
   70 R  21 3727 12/12/68 05:00:56 AD
   70 R  22 3760 12/12/68 05:07:29 AD
   70 R  23 3765 12/12/68 05:08:48 AD
   70 R  24 4016 12/12/68 05:15:21 AD
   70 R  25 4023 12/12/68 05:16:40 AN
   70 R  26 4054 12/12/68 05:23:13 BN

   71 R   1 4152 12/12/68 05:39:28 AN
   71 R   2 4203 12/12/68 05:46:02 AN
   71 R   3 4210 12/12/68 05:47:20 AD
   71 R   4 4241 12/12/68 05:53:53 AD
   71 R   5 4246 12/12/68 05:55:12 AD
   71 R   6 4277 12/12/68 06:01:45 BD
   71 R   7 4300 12/12/68 06:02:01 AD
   71 R   8 4374 12/12/68 06:17:45 CD

   72 R   1 4764 12/12/68 07:22:45 CN
   72 R   2 4770 12/12/68 07:23:48 CN
   72 R   3 5004 12/12/68 07:26:57 CDA

   73 R   1 5621 12/12/68 09:11:02 AD
   73 R   2 5625 12/12/68 09:12:05 CDA
```

```
CONTACT FR  SET            GMT
   74 R   1 6407 12/12/68 10:49:05 CD
   74 R   2 6501 12/12/68 11:04:17 CD
   74 R   3 6505 12/12/68 11:05:20 CDA

   76 S   1 7371 12/12/68 12:59:38 CDA
   76 S   2 7501 12/12/68 13:18:30 ADA
   76 S   3 7532 12/12/68 13:25:04 AD
   76 S   4 7537 12/12/68 13:26:22 AD
   76 S   5 7570 12/12/68 13:32:55 AD
   76 S   6 7575 12/12/68 13:34:14 AD
   76 S   7 7626 12/12/68 13:40:47 BN
   76 S   8 7627 12/12/68 13:41:03 AN
   76 S   9 7703 12/12/68 13:52:35 AN
   76 S  10 7734 12/12/68 13:59:08 AN
   76 S  11 7741 12/12/68 14:00:27 AN
   76 S  12 7772 12/12/68 14:07:00 AN
   76 S  13 7777 12/12/68 14:08:19 AD
   76 S  14 0030 12/12/68 14:14:52 BD
   76 S  15 0031 12/12/68 14:15:08 AD
   76 S  16 0152 12/12/68 14:36:22 ADA
   76 S  17 0203 12/12/68 14:42:55 ADA
   76 S  18 0210 12/12/68 14:44:14 ADA
   76 S  19 0241 12/12/68 14:50:47 ADA
   76 S  20 0246 12/12/68 14:52:06 BDA
   76 S  21 0407 12/12/68 15:17:31 AD
   76 S  22 0440 12/12/68 15:24:05 AN
   76 S  23 0445 12/12/68 15:25:23 AN
   76 S  24 0476 12/12/68 15:31:56 AN
   76 S  25 0503 12/12/68 15:33:15 AN
   76 S  26 0534 12/12/68 15:39:48 BN
   76 S  27 0535 12/12/68 15:40:04 AN
   76 S  28 0537 12/12/68 15:40:36 CN
   76 S  29 0543 12/12/68 15:41:38 CD

   78 S   1 1160 12/12/68 16:52:10 CDA
   78 S   2 2006 12/12/68 18:38:36 ANA
   78 S   3 2037 12/12/68 18:45:09 AN
   78 S   4 2044 12/12/68 18:46:28 AN
   78 S   5 2075 12/12/68 18:53:01 AN
   78 S   6 2102 12/12/68 18:54:19 BN
   78 S   7 2217 12/12/68 19:14:31 AD
   78 S   8 2250 12/12/68 19:21:04 AD
   78 S   9 2255 12/12/68 19:22:22 AD
   78 S  10 2306 12/12/68 19:28:56 AD
   78 S  11 2313 12/12/68 19:30:14 BD
****************************************************************************************************
```

Figure 3.1-6. DROOP Output (Overview): Frame Summary

```
INPUT        001
OUTPUT       001
SELECT
TC                15.7292778  2201.59798     WEEK   0,  PART 1
AXIS                7154.58
INCLINATION         34.997
MEAN ANOMALY        153.093
PERIGEE             282.85
RA NODE             74.57
D(RA NODE)          -5.4767
DAY OF EPOCH        342       12/07/68
MIN OF EPOCH        532.0
START
PERIOD            100.15850
EPOCH        2440197.8694444444

STRIPR RUN ID =T00008   04/27/72   13:39:04

*** END OF FILE ***
```


Figure 3.1-7. DROOP Output (Overview): Spacecraft Ephemeris

3.2 DESCRIPTION OF THE OBJECT DATA

This section describes those portions of the DROOP results that summarize observations of a particular object. These data are contained on two pages preceding each set of individual observations (frames).

The first page (Figure 3.2-1) summarizes all observations of the object in question for a particular set of frames. The first line (a) of this page gives the name of the object, the date and time span of the observations summarized, the orbit number, ground station initial, and week number. After skipping a line, the next line (b) begins with the letter 'S.' This is a remnant from earlier software and can be ignored. Following the letter 'S,' the object name is repeated, followed by the right ascension/declination of the object, its magnitude, spectral type, luminosity class, peculiarities, visual magnitude, B-V, U-B, and spacecraft pitch and yaw (or other comments). Note that if the B-V or U-B values are not known, those columns will contain zeros.

On the next line (C), the target (object) longitude and latitude are given in both ecliptic coordinates and galactic coordinates. On the following line, after the word 'target,' the spacecraft roll angle, the slit position angle, the distance of the telescopes from the Sun, and the distance from the Sun in ecliptic longitude are given. The roll angle (C) is defined as the angle between the spacecraft y-(pitch) axis and the celestial equator, measured in the y-z (pitch-yaw) plane.

Between two lines of asterisks, the calibration data (table D) presented earlier in the overview data section are repeated. Note that the analog value for ST4 is meaningless since that channel failed.

Following the second line of asterisks is a line defining the 'OAO magnitude.' Note that the 'LOG (CONST)' is the same as the 'LOG (DELTA)' mentioned in the DROOP description (see Figure 3.1-2).

Following this definition, the data from the entire set of observations (all relevant frames) were averaged individually for each stellar photometer and each filter position (including dark current data and calibration data).

For each photometer and each filter position (arrayed as columns), four quantities were averaged. The analog values determined for (DATA - DK)/(CAL - DK) are listed first, followed by the digital analog value of (DATA - DK)/(CAL - DK). (Note: These values were derived by using the volts/overflow and offsets in conjunction with the analog data). These are followed by the digital values of (DATA - DK)/(CAL - DK), and in the case of filter positions only (i.e., not in the case of dark current measurements or calibration data), the

```
A  SUMMARY FOR   IOT CAR    GMT=12/11/68  17:46:24 TO 18:00:49                                         63 S  WEEK(   1)
B  S IOT CAR  9 15.76 -59  3.5  2.2 FO  I           2.25    0.18    0.11 P=   0 Y=    0
   TARGET (ECLIPTIC)  LONG 184 37 36  LAT -67  6 37     TARGET (GALACTIC)  LONG 278 27 20  LAT - 7  0 20
C  TARGET      ROLL ANGLE  -85.80     SLIT POS ANGLE  355.80     DIST FROM SUN   84.29     DIST FROM SUN (ECL LONG)   75.17

   ****************************************************************************************************

   CALIBRATION DATA CHOSEN FOR THIS DATA TAPE  (AN AVERAGE OF CAL-SLIDE MINUS DARK FOR THE WHOLE TAPE IS USED)
   ST 1          ANALOG      .94 +OR-    .017 VOLTS                      DIGITAL  168.99 +OR-  2.471 COUNTS
D  ST 2          ANALOG      .34 +OR-    .007 VOLTS                      DIGITAL   38.74 +OR-   .825 COUNTS
   ST 3          ANALOG      .17 +OR-    .002 VOLTS                      DIGITAL  240.71 +OR-  1.680 COUNTS
   ST 4          ANALOG     1.00 +OR-    .000 VOLTS                      DIGITAL  137.98 +OR-   .769 COUNTS

   ****************************************************************************************************
   OAO-MAG= -2.5 LOG(DIGITAL) -2.5 LOG(CONST), WHERE CONST IS THE SENSITIVITY OF THE GIVEN FILTER RELATIVE TO 3320 FILTER
                        1                  2                    3                    4                   5
   STELLAR 1       (4) 2980 ANG         (1) 3320 ANG         (3) 4250 ANG         (2) DARK            (5) CAL

E  ANALOG                         .158+02+-   .61-01   .140+03+-   .98-01   .497-01+-   .80-03   .851+00+-   .51-02 V
   DIG-ANA                        .167+02+-   .31+00   .141+03+-   .21+01   .542-01+-   .16-02   .165+03+-   .97+00 C
   DIGITAL                        .167+02+-   .26+00   .140+03+-   .21+01   .568-01+-   .12-02   .165+03+-   .37+00 C
   OAO-MAG                      -.30571+01           -.36668+01


   STELLAR 2       (1) 2030 ANG         (5) 2390 ANG         (2) 2940 ANG         (3) DARK            (4) CAL

   ANALOG                         .406+01+-   .22-01   .153+02+-   .12+00   .604-01+-   .20-02   .323+00+-   .10-02 V
   DIG-ANA                        .563+01+-   .15+00   .211+02+-   .66+00   .586-01+-   .33-02   .367+02+-   .12+00 C
   DIGITAL                        .653+01+-   .14+00   .217+02+-   .47+00   .662-01+-   .16-02   .380+02+-   .70-01 C
   OAO-MAG                      -.31904+01           -.34497+01


   STELLAR 3       (5) 1680 ANG         (1) 1910 ANG         (2) 2460 ANG         (4) DARK            (3) CAL

   ANALOG                         .197+00+-   .31-02   .122+01+-   .20-02   .280-01+-   .13-02   .177+00+-   .30-03 V
   DIG-ANA                        .414+00+-   .98-02   .266+01+-   .23-01   .441-01+-   .32-02   .539+03+-   .93+00 C
   DIGITAL                        .452+00+-   .36-02   .267+01+-   .19-01   .143-02+-   .91-04   .241+03+-   .21+00 C
   OAO-MAG                      -.32487+01           -.31054+01


   STELLAR 4       (4) 1330 ANG         (3) 1430 ANG         (1) 1550 ANG         (5) DARK            (2) CAL

   ANALOG   .230+00+-   .59-01 V                     .335-01+-   .86-02 V
   DIG-ANA
   DIGITAL  .104+00+-   .63-03                      -.106-02+-   .19-04   .136-02+-   .22-04   .135+03+-   .14+00 C
   OAO-MAG -.41557+01                               -.52850+01

   ****************************************************************************************************
```

Figure 3.2-1. DROOP Output (Object): Summary of a Set of Observations of One Object During One Contact values for the derived OAO magnitude. Note that the dark current values are defined as the ratios of DK to CAL - DK, in volts or counts, and that the calibration data are actually values of CAL - DK in volts or counts (see Figure 3.2-1). These may be compared with the values listed on the table of calibration data after the half-life of the strontium^{90} source is taken into account by the following formula:

$$(CAL - DK)_{t=0} = (CAL - DK)_t \times e^{(orbit \times 5.27 \times 10^{-6})} \qquad (3.2\text{-}1)$$

Note that the data from Stellar Photometer 4 do not include digitized analog data and that the analog data were estimated from models of stellar spectra.

The second page (Figure 3.2-2) iterates the identification line A, beginning with the vestigial 'S,' but with the date and time period covered added to the end. In line B are the analog voltages (computed at Exposure/gain 2) for the four instruments and each filter predicted from the model stellar spectra previously alluded to.

The curve fits for the dark data are given next. Wherever possible, a second-order parabolic fit was determined using the least-squares method, which fits the dark current as a function of time in minutes from the start of the first measurement (t=0). The date and time for t=0 are given on the upper right-hand corner of the plot (item(E)). If the second-order fit was not possible, a linear fit was determined for the dark current as a function of time, and if that failed, the average was simply used. Whenever possible, data from the four stellar photometers were used independently (the type of process is then labeled 'individual fitting'). If necessary, the data from the different photometers were merged by converting all data to their equivalent ST1 values, using the interrelations listed earlier (see Figure 3.1-1). In the latter case, the process is called 'collective fitting.' These coefficients and the root-mean-square error in the residuals (the residual is the difference between the measured value and that calculated using the curve fit) are given in tabular form for each detector, and the resulting dark current is in counts at Exposure/gain 2.

Following this table, dark current (listed as both raw observed data, where 1=ST1, 2=ST2, etc., and derived data, where A=ST1, B=ST2, etc.) is shown against time on a plot generated by a line printer, with a vertical line within the graph indicating the time of the last observation in the sequence of frames.

```
(A) STAR  S IOT CAR  9 15.76 -59  3.5  2.2 FO  (        2.25   0.18   0.11 P=   0 Y=   0    12/11/68  17:46:24 TO 18: 0:49
(B) ANALOG VOLTAGES COMPUTED FOR GAIN 2 USING MODELS, UPDATE NO. 1,  NOV 1970
    ST1*  22.63 206.39  11.88       ST2*     .69   6.26   1.09       ST3*    .02     .18     .01       ST4*     .02     .03     .16
(C) CURVE FIT FOR DARK DATA          T**2            T               CONST           ERROR                 TYPE OF PROCESS
                   STELLAR 1        .00000      -.65133+00       .17539+02       .22423+00              COLLECTIVE FITS
                   STELLAR 2        .00000      -.11561+00       .29581+01       .39801-01              COLLECTIVE FITS
                   STELLAR 3        .00000      -.65133-03       .39754+00       .22423-03              COLLECTIVE FITS
                   STELLAR 4        .00000       .14655-02       .37304+00       .50452-03              COLLECTIVE FITS
     1
              PLOT OF DARK DATA AND CURVE FIT CONVERTED TO E2 AND ST1, VERSUS TIME.    T=0 IS AT 12/11/68 17:46:24
```

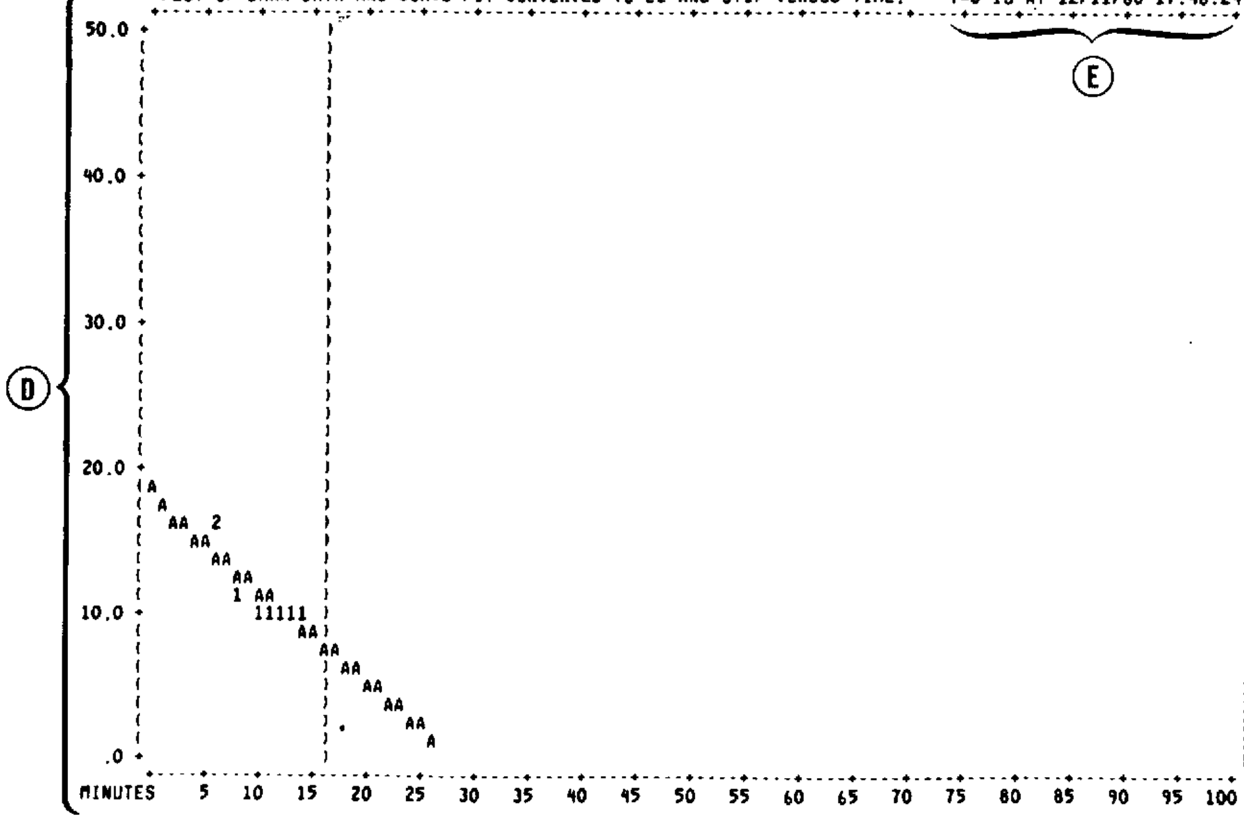


Figure 3.2-2. DROOP Output (Object): Curve Fit for Dark Data

3.3 DESCRIPTION OF THE FRAME DATA

This portion of the DROOP results describes the data from each individual observing run. These data were not reduced if the observations were: (a) not made in the stellar photometer mode, (b) made during predicted spacecraft day, or (c) made when the spacecraft was within the predicted South Atlantic Geomagnetic Anomaly. Otherwise, the individual frame data include both raw and reduced stellar photometer data.

Data rejected because they were taken during predicted spacecraft day are illustrated in Figure 3.3-1.

Line A gives the contact orbit number, the ground station abbreviation, and the frame number. Line B gives the reason this frame was rejected (in this case, because the spacecraft was in daylight). The group of lines labelled C gives the raw stellar photometer data, nebular photometer data, and some spectrometer data. The second column, headed M, gives the mode of operation (in this case, Mode A). The columns headed E give the exposure/gain used for that subframe. The column headed F gives the filter position number. The column headed A gives the aperture used (L= large, S=small). The columns headed ANA give the analog voltages. The columns headed DIG give the raw digital counts. The columns headed C are indicators of collimation trouble (N signifies 'normal').

The spectrometer data in the rightmost six columns should be disregarded. They will be described in another document. The group of lines labelled D contains spectrometer data, power supply and thermal data, orbital information, and a flag indicating the spacecraft was in daylight or the South Atlantic Geomagnetic Anomaly, if applicable. These lines can usually be disregarded.

Data rejected because they were taken when the spacecraft was within the predicted South Atlantic Geomagnetic Anomaly are illustrated in Figure 3.3-2. Items A, C, and D are identical to those described above in Figure 3.3-1. Item B differs only in that the reason for rejection was that the spacecraft was in the Anomaly rather than daylight.

Data rejected because they were not taken in Mode A are illustrated in Figures 3.3-3a and 3.3-3b. Again, Items A, C, and D are essentially the same as in Figure 3.3-1, except that the tables of Items C and D are much longer because the spacecraft was in the spectrometer mode. Item B is different only in that the reason for rejection was that the spacecraft was not in Mode A.

A sample of reduced stellar photometer data is shown in Figure 3.3-4. Frames such as this one are the essence of each data set.

```
A   ***********************************************  63 SNT,  FRAME 12 ***********************************************
    STAR     S IOT CAR  9 15.76 -59  3.5  2.2 FO  I          2.25   0.18   0.11 P=   0 Y=   0  CONTACT    63  S( 6 )FRAME   12
    SPACECRAFT  DAY.        SUB-SAT RANGE 134  34 TO 155  35    AZIMUTH-ZEN DIST 172.70  93.77 TO 184.58  94.13
    TARGET (ECLIPTIC)  LONG 184 37 36  LAT -67  6 37      TARGET (GALACTIC)  LONG 278 27 20  LAT - 7  0 20
    TARGET      ROLL ANGLE  -85.80      SLIT POS ANGLE  355.80     DIST FROM SUN   84.29     DIST FROM SUN (ECL LONG)   75.18
    CM COM B NEB(E2,F1) NOCHANGEAPERTURE NEITHERREADOUT VCOD                          ADD=253 GMT=12/11/68 18:02:08(SET=7006)
    CM COM A ST1(E1,F4) ST2(E2,F1) ST3(E4,F5) ST4(E4,F3) NOCYCLE                      ADD=254 GMT=12/11/68 18:02:08(SET=7006)
    DS COM A ST1(E1,F4) ST2(E2,F1) ST3(E4,F5) ST4(E4,F3) NOCYCLE    IND=03617-04107 ADD=254 GMT=12/11/68 18:02:08(SET=7006)
B   ERROR      *** THIS FRAME WAS REJECTED BECAUSE IT WAS OBSERVED IN DAYLIGHT (DROOP)

              STELLAR 1          STELLAR 2          STELLAR 3          STELLAR 4            NEBULAR             SPECTROMETER
        M  E F A  ANA DIG C   E F A  ANA DIG C   E F A  ANA DIG C   E F A  ANA DIG C   E F A  ANA DIG SP E S  QUADRANT   ANA DIG
    1.  A  1 4 L 1.00 209 N   2 1 L  .92 174 N   4 5 L  .56 105 N   4 3 L  .00  47 N   2 1 L 1.34 254  2 4 L 1750-2000   .90 149
    2.  A  1 4 L 1.02 208 N   2 1 L  .92 172 N   4 5 L  .58 107 N   4 3 L  .00  49 N   2 1 L 1.34 241  2 4 L             .90 155
C   3.  A  1 4 L 1.02 212 N   2 1 L  .90 170 N   4 5 L  .54 103 N   4 3 L  .00  50 N   2 1 L 1.36 248  2 4 L             .98 169
    4.  A  1 4 L 1.00 209 N   2 1 L  .94 169 N   4 5 L  .54 105 N   4 3 L  .00  54 N   2 1 L 1.26 240  2 4 L             .92 180
    5.  A  1 4 L 1.00 219 N   2 1 L  .92 169 N   4 5 L  .56 107 N   4 3 L  .00  57 N   2 1 L 1.34 216  2 4 L             .94 186
    6.  A  1 4 L 1.04 209 N   2 1 L  .88 168 N   4 5 L  .52 102 N   4 3 L  .00  63 N   2 1 L  .70 239  2 4 L             .98 204

           SP 1    SP 2   +10 V   -10 V   +15 V   -15 V    HI V   CON EL NEB TOP PRI STR    AZIMUTH ZEN DIST     SUB-SAT
    1.      .18     .90    2.72    2.80    3.76    2.50    2.80    3.52    3.94    3.80      172.70   93.77      134  34 N
    2.      .16     .90    2.72    2.80    3.74    2.50    2.80    3.52    3.94    3.80      175.02   93.88      138  34 N
D   3.      .18     .98    2.72    2.78    3.74    2.50    2.80    3.52    3.94    3.80      177.39   93.97      142  35 N
    4.      .16     .92    2.72    2.80    3.74    2.50    2.80    3.54    3.92    3.80      179.79   94.04      147  35 N
    5.      .16     .94    2.70    2.80    3.74    2.50    2.80    3.54    3.92    3.80      182.19   94.09      151  35 N
    6.      .24     .98    2.70    2.80    3.74    2.50    2.80    3.54    3.92    3.82      184.58   94.13      155  35 D
    DUMP PROCESSED: WDSC
    *****************************************************************************************************************
```

Figure 3.3-1. DROOP Output (Frame): Frame Rejected Because It Was Observed in Daylight

```
     *********************************************  63 SNT,  FRAME  3 *********************************************
(A)  STAR    S BET CAR  9 12.69 -69 30.4  1.6 A1  IV  S     1.68   0.00   0.02 P=   0 Y=   0  CONTACT    63  S( 6)FRAME    3
     SPACECRAFT  DAY.       SUB-SAT RANGE 351 -35 TO 354 -34     AZIMUTH-ZEN DIST 175.34  75.51 TO 174.23  75.58      ANOMALY
     TARGET (ECLIPTIC)  LONG 211 16 29  LAT -72 13 40     TARGET (GALACTIC)  LONG 285 58 47  LAT -14 24  6
     TARGET     ROLL ANGLE  -79.50     SLIT POS ANGLE  349.50     DIST FROM SUN   78.33     DIST FROM SUN (ECL LONG)   48.50
     CM COM B NEB(E1,F4) NOCHANGEAPERTURE NEITHERREADOUT VCOO                          ADD=121 GMT=12/11/68 17:18:05(SET=6536)
     CM COM A ST1(E1,F1) ST2(E3,F3) ST3(E2,F2) ST4(E3,F5) NOCYCLE                      ADD=122 GMT=12/11/68 17:18:05(SET=6536)
     DS COM A ST1(E1,F1) ST2(E3,F3) ST3(E2,F2) ST4(E3,F5) NOCYCLE     IND=00427-00717 ADD=122 GMT=12/11/68 17:18:05(SET=6536)
(B)  ERROR       *** THIS FRAME WAS REJECTED BECAUSE IT IS IN THE ANOMALY (DROOP)

          STELLAR 1           STELLAR 2           STELLAR 3           STELLAR 4           NEBULAR               SPECTROMETER
        M  E F A  ANA DIG C  E F A  ANA DIG C  E F A  ANA DIG C  E F A  ANA DIG C  E F A  ANA DIG SP E S  QUADRANT  ANA DIG
     1. A  1 1 L 5.04 253 N  3 3 L 5.04  99 N  2 2 L 1.80 172 N  3 5 L  .00  30 N  1 4 L 5.04 161  2 4 L 1750-2000 5.04  96
     2. A  1 1 L 5.04  31 N  3 3 L 5.04  82 N  2 2 L 1.78 172 N  3 5 L  .00  28 N  1 4 L 5.04 200  2 4 L           5.04  99
(C)  3. A  1 1 L 5.04  15 N  3 3 L 4.40  69 N  2 2 L 1.78 184 N  3 5 L  .00  28 N  1 4 L 5.04 225  2 4 L           5.04  40
     4. A  1 1 L 5.04   4 N  3 3 L 1.62  53 N  2 2 L 1.76 156 N  3 5 L  .00  26 N  1 4 L 5.04 213  2 4 L           5.04 236
     5. A  1 1 L 5.04   5 N  3 3 L 1.44  44 N  2 2 L 1.78 161 N  3 5 L  .00  26 N  1 4 L 5.04 195  2 4 L           5.04 184
     6. A  1 1 L 5.04   3 N  3 3 L 1.40  35 N  2 2 L 1.80 149 N  3 5 L  .00  25 N  1 4 L 5.04 211  2 4 L           5.04 143

           SP 1    SP 2   +10 V   -10 V   +15 V   -15 V    HI V   CON EL NEB TOP PRI STR    AZIMUTH ZEN DIST    SUB-SAT
     1.    5.04    5.04    2.72    2.80    3.78    2.48    2.92    3.54    3.92    3.80      175.34   75.51     351 -35AD
     2.    5.04    5.04    2.70    2.80    3.76    2.48    2.94    3.52    3.92    3.82      175.12   75.52     352 -34AD
(D)  3.    5.04    5.04    2.70    2.80    3.76    2.48    2.92    3.54    3.92    3.80      174.89   75.53     352 -34AD
     4.    5.04    5.04    2.70    2.80    3.78    2.48    2.94    3.54    3.92    3.82      174.67   75.55     353 -34AD
     5.    5.04    5.04    2.70    2.80    3.76    2.48    2.92    3.54    3.92    3.80      174.45   75.56     354 -34AD
     6.    5.04    5.04    2.72    2.80    3.76    2.48    2.92    3.54    3.90    3.80      174.23   75.58     354 -34AD

     DUMP PROCESSED: WDSC
     ***************************************************************************************************************
```


Figure 3.3-2. DROOP Output (Frame): Frame Rejected Because It Was Observed in Predicted South Atlantic Geomagnetic Anomaly

(A)

```
*********************************************   63 SNT,  FRAME 14 *****************************************************
STAR     S IOT CAR  9 15.76 -59  3.5  2.2 FO  I         2.25   0.18   0.11 P=   0 Y=   0  CONTACT     63  S( 6 )FRAME    14
SPACECRAFT  DAY.         SUB-SAT RANGE 165  34 TO 260 -20     AZIMUTH-ZEN DIST 189.88   94.14 TO 205.85  88.24
TARGET (ECLIPTIC)  LONG 184 37 36  LAT -67  6 37       TARGET (GALACTIC)  LONG 278 27 20  LAT - 7  0 20
TARGET       ROLL ANGLE  -85.80      SLIT POS ANGLE  355.80      DIST FROM SUN   84.30      DIST FROM SUN (ECL LONG)   75.20
CM COM C SP1(E3,SN) DIRECTION(L) NUMBEROFSTEPS(002)                              ADD=256 GMT=12/11/68 18:08:57(SET=7040)
CM COM C SP1(E4,SN) DIRECTION(L) NUMBEROFSTEPS(026)                              ADD=260 GMT=12/11/68 18:10:00(SET=7044)
DS COM C SP1(E4,SN) DIRECTION(L) NUMBEROFSTEPS(026)             IND=04514-05236 ADD=260 GMT=12/11/68 18:10:00(SET=7044)
ERROR         *** THIS FRAME WAS REJECTED BECAUSE IT IS NOT A MODE A (DROOP)
```

(B)

(C)

		STELLAR 1						STELLAR 2						STELLAR 3						STELLAR 4						NEBULAR								SPECTROMETER		
	M	E	F	A	ANA	DIG	C	E	F	A	ANA	DIG	C	E	F	A	ANA	DIG	C	E	F	A	ANA	DIG	C	E	F	A	ANA	DIG	SP	E	S	QUADRANT	ANA	DIG
1.	C	1	4	L	.18	4	N	2	1	L	.08	4	N	4	5	L	.22	43	N	4	3	L	.00	58	N	2	2	L	2.26	217	1	4	S	2000-2500	.46	61
2.	C	1	4	L	1.02	8	N	2	1	L	.76	9	N	4	5	L	.54	201	N	4	3	L	.00	91	N	2	2	L	2.38	170	1	4	S		.84	139
3.	C	1	4	L	1.04	220	N	2	1	L	.80	152	N	4	5	L	.54	127	N	4	3	L	.00	97	N	2	2	L	3.60	35	1	4	S		2.72	30
4.	C	1	4	L	1.06	215	N	2	1	L	.80	150	N	4	5	L	.58	122	N	4	3	L	.00	108	N	2	2	L	5.04	135	1	4	S		5.04	107
5.	C	1	4	L	.36	227	N	2	1	L	.18	150	N	4	5	L	.26	189	N	4	3	L	.00	143	N	2	2	L	5.04	163	1	4	S		5.04	182
6.	C	1	4	L	.66	69	N	2	1	L	.40	37	N	4	5	L	.26	80	N	4	3	L	.00	170	N	2	2	L	5.04	14	1	4	S		5.04	238
7.	C	1	4	L	.98	142	N	2	1	L	.70	78	N	4	5	L	.26	103	N	4	3	L	.00	182	N	2	2	L	5.04	222	1	4	S		5.04	142
8.	C	1	4	L	1.46	238	N	2	1	L	1.04	147	N	4	5	L	.28	110	N	4	3	L	.00	196	N	2	2	L	5.04	45	1	4	S		5.04	210
9.	C	1	4	L	2.90	100	N	2	1	L	2.30	232	N	4	5	L	.64	149	N	4	3	L	.00	205	N	2	2	L	5.04	169	1	4	S		5.04	164
10.	C	1	4	L	3.46	205	N	2	1	L	2.66	239	N	4	5	L	.68	21	N	4	3	L	.00	219	N	2	2	L	5.04	87	1	4	S		5.04	180
11.	C	1	4	L	4.00	93	N	2	1	L	3.36	78	N	4	5	L	.70	26	N	4	3	L	.00	234	N	2	2	L	5.04	156	1	4	S		5.04	235
12.	C	1	4	L	4.62	200	N	2	1	L	4.14	245	N	4	5	L	.70	12	N	4	3	L	.00	249	N	2	2	L	5.04	150	1	4	S		5.04	95
13.	C	1	4	L	5.04	66	N	2	1	L	4.98	150	N	4	5	L	.72	51	N	4	3	L	.00	12	N	2	2	L	5.04	60	1	4	S		5.04	209
14.	C	1	4	L	5.04	176	N	2	1	L	5.04	104	N	4	5	L	.80	122	N	4	3	L	.00	29	N	2	2	L	5.04	1	1	4	S		5.04	154
15.	C	1	4	L	5.04	25	N	2	1	L	5.04	61	N	4	5	L	.82	135	N	4	3	L	.00	39	N	2	2	L	5.04	40	1	4	S		5.04	64
16.	C	1	4	L	5.04	108	N	2	1	L	5.04	16	N	4	5	L	.86	147	N	4	3	L	.00	56	N	2	2	L	5.04	30	1	4	S		5.04	250
17.	C	1	4	L	5.04	136	N	2	1	L	5.04	162	N	4	5	L	.82	154	N	4	3	L	.00	61	N	2	2	L	5.04	100	1	4	S		5.04	42
18.	C	1	4	L	5.04	244	N	2	1	L	5.04	212	N	4	5	L	.82	143	N	4	3	L	.00	69	N	2	2	L	5.04	115	1	4	S		5.04	128
19.	C	1	4	L	5.04	175	N	2	1	L	5.04	30	N	4	5	L	.80	107	N	4	3	L	.00	82	N	2	2	L	5.04	89	1	4	S		5.04	111
20.	C	1	4	L	5.04	116	N	2	1	L	5.04	208	N	4	5	L	.78	101	N	4	3	L	.00	98	N	2	2	L	5.04	108	1	4	S	2500-3000	5.04	145
21.	C	1	4	L	5.04	233	N	2	1	L	5.04	4	N	4	5	L	.78	103	N	4	3	L	.00	109	N	2	2	L	5.04	98	1	4	S		5.04	194
22.	C	1	4	L	5.04	71	N	2	1	L	5.04	89	N	4	5	L	.84	143	N	4	3	L	.00	121	N	2	2	L	5.04	2	1	4	S		5.04	255
23.	C	1	4	L	5.04	121	N	2	1	L	5.04	165	N	4	5	L	.90	173	N	4	3	L	.00	121	N	2	2	L	5.04	146	1	4	S		5.04	252
24.	C	1	4	L	5.04	143	N	2	1	L	5.04	138	N	4	5	L	.88	169	N	4	3	L	.00	127	N	2	2	L	5.04	190	1	4	S		5.04	65
25.	C	1	4	L	5.04	201	N	2	1	L	5.04	17	N	4	5	L	.86	170	N	4	3	L	.00	145	N	2	2	L	5.04	158	1	4	S		5.04	153
26.	A	1	4	L	5.04	218	N	2	1	L	5.04	27	N	4	5	L	.86	166	N	4	3	L	.00	148	N	2	2	L	5.04	93	1	4	S		5.04	212
27.	A	1	4	L	5.04	233	N	2	1	L	5.04	37	N	4	5	L	.88	165	N	4	3	L	.00	158	N	2	2	L	5.04	162	1	4	S		5.04	21
28.	A	1	4	L	5.04	219	N	2	1	L	5.04	80	N	4	5	L	.88	162	N	4	3	L	.00	166	N	2	2	L	5.04	124	1	4	S		5.04	192
29.	A	1	4	L	5.04	13	N	2	1	L	5.04	157	N	4	5	L	.88	167	N	4	3	L	.00	172	N	2	2	L	5.04	120	1	4	S		5.04	48
30.	A	1	4	L	5.04	225	N	2	1	L	5.04	243	N	4	5	L	.96	173	N	4	3	L	.00	183	N	2	2	L	5.04	44	1	4	S		5.04	205

(D)

	SP 1	SP 2	+10 V	-10 V	+15 V	-15 V	HI V	CON EL	NEB TOP	PRI STR	AZIMUTH	ZEN DIST	SUB-SAT		
1.	.46	.52	2.70	2.80	3.74	2.50	2.80	3.54	3.92	3.80	189.88	94.14	165	34	D
2.	.84	.94	2.70	2.80	3.74	2.50	2.82	3.54	3.94	3.80	192.07	94.11	170	33	D
3.	2.72	1.10	2.72	2.78	3.76	2.50	2.82	3.52	3.92	3.80	194.16	94.07	174	32	D
4.	5.04	1.22	2.70	2.80	3.74	2.50	2.86	3.54	3.94	3.80	196.14	94.01	178	31	D
5.	5.04	.76	2.72	2.80	3.74	2.50	2.90	3.54	3.92	3.80	198.00	93.93	182	30	D
6.	5.04	.94	2.72	2.78	3.74	2.50	2.88	3.52	3.92	3.80	199.74	93.83	186	28	D
7.	5.04	1.48	2.72	2.80	3.76	2.50	2.90	3.54	3.94	3.80	201.35	93.71	189	27	D
8.	5.04	2.70	2.72	2.80	3.76	2.48	2.90	3.54	3.92	3.80	202.82	93.58	193	25	D
9.	5.04	4.76	2.70	2.80	3.76	2.48	2.88	3.52	3.94	3.80	204.16	93.43	196	24	D
10.	5.04	5.04	2.70	2.80	3.76	2.50	2.90	3.54	3.92	3.80	205.38	93.26	200	22	D
11.	5.04	5.04	2.70	2.80	3.76	2.50	2.90	3.52	3.94	3.80	206.46	93.08	203	20	D
12.	5.04	5.04	2.70	2.80	3.76	2.50	2.90	3.52	3.94	3.80	207.42	92.89	206	18	D
13.	5.04	5.04	2.70	2.80	3.76	2.48	2.90	3.52	3.94	3.80	208.25	92.68	210	16	D

Figure 3.3-3a. DROOP Output (Frame): Frame Rejected Because It Was Not in Mode A

14.	5.04	5.04	2.72	2.80	3.76	2.48	2.90	3.52	3.92	3.80	208.97	92.47	213	14 D
15.	5.04	5.04	2.70	2.80	3.76	2.48	2.90	3.52	3.92	3.80	209.57	92.24	216	12 D
16.	5.04	5.04	2.72	2.80	3.76	2.50	2.90	3.52	3.92	3.80	210.06	92.00	219	10 D
17.	5.04	5.04	2.70	2.80	3.76	2.48	2.90	3.52	3.92	3.82	210.44	91.75	222	8 D
18.	5.04	5.04	2.72	2.78	3.76	2.48	2.90	3.52	3.94	3.80	210.71	91.49	225	6 D
19.	5.04	5.04	2.70	2.80	3.76	2.48	2.92	3.54	3.92	3.80	210.88	91.23	227	4 D
20.	5.04	5.04	2.72	2.78	3.76	2.48	2.92	3.52	3.94	3.80	210.94	90.96	230	1 D
21.	5.04	5.04	2.70	2.80	3.76	2.48	2.92	3.52	3.94	3.80	210.91	90.69	233	-1 D
22.	5.04	5.04	2.70	2.80	3.76	2.48	2.92	3.52	3.92	3.80	210.77	90.41	236	-3 D
23.	5.04	5.04	2.72	2.80	3.76	2.48	2.92	3.52	3.94	3.80	210.53	90.13	239	-5 D
24.	5.04	5.04	2.70	2.80	3.76	2.46	2.92	3.52	3.92	3.80	210.19	89.86	242	-7 D
25.	5.04	5.04	2.70	2.80	3.76	2.48	2.94	3.54	3.92	3.80	209.74	89.58	245	-9 D
26.	5.04	5.04	2.70	2.78	3.76	2.46	2.92	3.52	3.92	3.80	209.19	89.30	248	-12 D
27.	5.04	5.04	2.72	2.80	3.76	2.46	2.92	3.54	3.92	3.82	208.52	89.03	251	-14 D
28.	5.04	5.04	2.72	2.78	3.76	2.48	2.92	3.52	3.94	3.80	207.75	88.76	254	-16 D
29.	5.04	5.04	2.72	2.80	3.76	2.48	2.92	3.52	3.92	3.82	206.86	88.50	257	-18 D
30.	5.04	5.04	2.72	2.78	3.76	2.48	2.94	3.52	3.94	3.80	205.85	88.24	260	-20 D

D

DUMP PROCESSED: WDSC

****

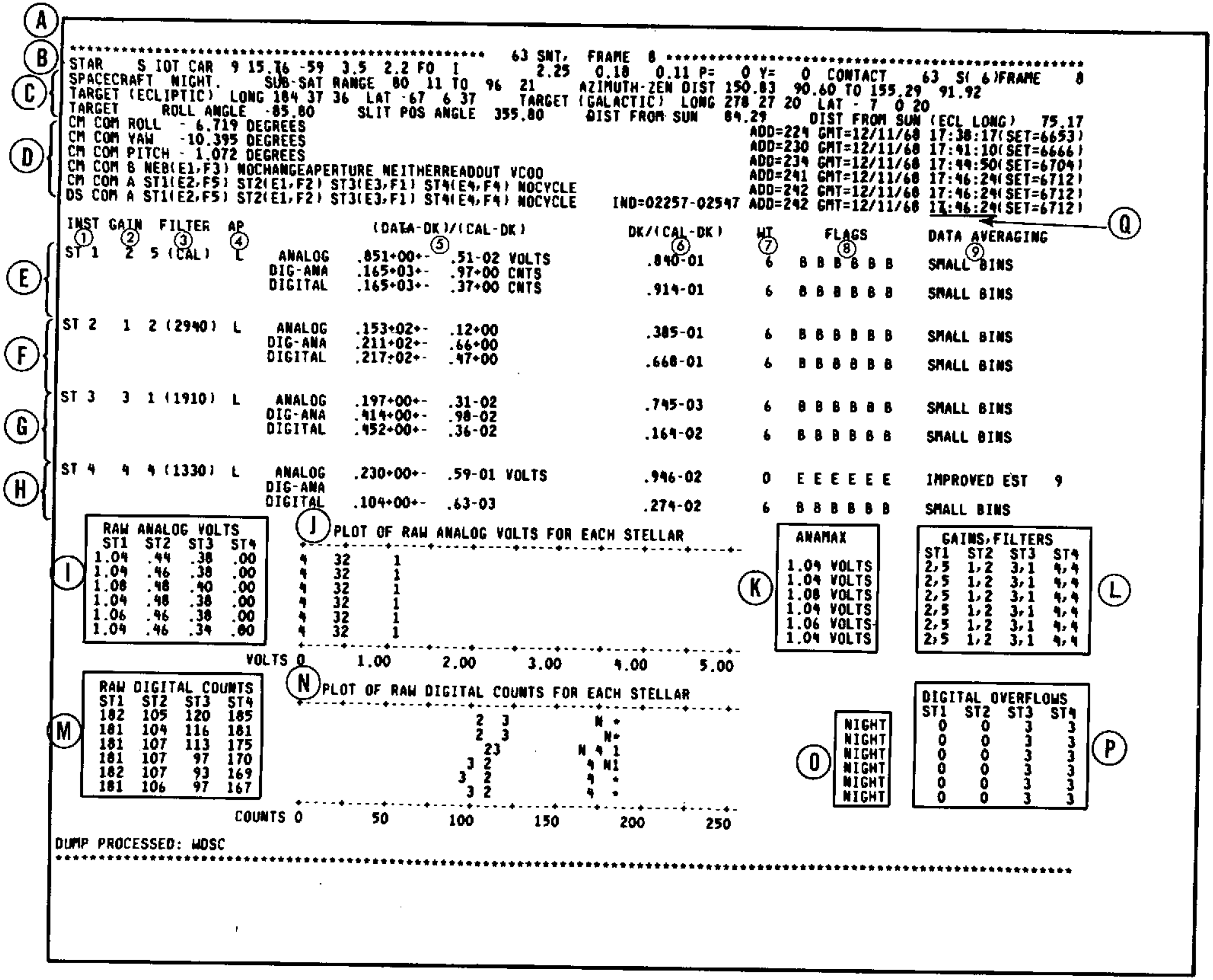
1 CONTACTS FOUND. 14 WEP FRAMES FOUND. ERRORS: 0 MODE, 0 STRUCTURE, 0 DIGITAL SEQUENCE, 1 FRAME LENGTH.

28 WEP COMMANDS FOUND. ERRORS: 0 MISSING COMMANDS, 0 ERRONEOUS COMMANDS.

2 TARGETS OBSERVED.

****

Figure 3.3-3b. DROOP Output (Frame): Frame Rejected Because It Was Not in Mode A



```
********************************************  63 SNT,  FRAME  8 **********************************************
STAR      S IOT CAR  9 15.16 -59  3.5  2.2 FO  I
SPACECRAFT  NIGHT.        SUB-SAT RANGE  80  11 TO  96  21       2.25   0.18   0.11 P=   0 Y=   0  CONTACT    63  S( 6)FRAME    8
TARGET (ECLIPTIC)  LONG 184 37 36  LAT -67  6 37       AZIMUTH-ZEN DIST 150.83  90.60 TO 155.29  91.92
TARGET       ROLL ANGLE  -85.80      SLIT POS ANGLE  355.80     TARGET (GALACTIC)  LONG 278 27 20  LAT - 7  0 20
CM COM ROLL  - 6.719 DEGREES                                    DIST FROM SUN   84.29    DIST FROM SUN (ECL LONG)   75.17
CM COM YAW   -10.395 DEGREES                                               ADD=224 GMT=12/11/68 17:38:17(SET=6653)
CM COM PITCH - 1.072 DEGREES                                               ADD=230 GMT=12/11/68 17:41:10(SET=6666)
CM COM B NEB(E1,F3) NOCHANGEAPERTURE NEITHERREADOUT VCOO                   ADD=234 GMT=12/11/68 17:44:50(SET=6704)
CM COM A ST1(E2,F5) ST2(E1,F2) ST3(E3,F1) ST4(E4,F4) NOCYCLE               ADD=241 GMT=12/11/68 17:46:24(SET=6712)
DS COM A ST1(E2,F5) ST2(E1,F2) ST3(E3,F1) ST4(E4,F4) NOCYCLE               ADD=242 GMT=12/11/68 17:46:24(SET=6712)
                                                    IND=02257-02547   ADD=242 GMT=12/11/68 17:46:24(SET=6712)

INST GAIN FILTER  AP        (DATA-DK)/(CAL-DK)         DK/(CAL-DK)  WT     FLAGS        DATA AVERAGING
ST 1   2   5 (CAL)  L  ANALOG   .851+00+- .51-02 VOLTS  .840-01      6  B B B B B B   SMALL BINS
                       DIG-ANA  .165+03+- .97+00 CNTS
                       DIGITAL  .165+03+- .37+00 CNTS   .914-01      6  B B B B B B   SMALL BINS

ST 2   1   2 (2940) L  ANALOG   .153+02+- .12+00        .385-01      6  B B B B B B   SMALL BINS
                       DIG-ANA  .211+02+- .66+00
                       DIGITAL  .217+02+- .47+00        .668-01      6  B B B B B B   SMALL BINS

ST 3   3   1 (1910) L  ANALOG   .197+00+- .31-02        .745-03      6  B B B B B B   SMALL BINS
                       DIG-ANA  .414+00+- .98-02
                       DIGITAL  .452+00+- .36-02        .164-02      6  B B B B B B   SMALL BINS

ST 4   4   4 (1330) L  ANALOG   .230+00+- .59-01 VOLTS  .946-02      0  E E E E E E   IMPROVED EST    9
                       DIG-ANA
                       DIGITAL  .104+00+- .63-03        .274-02      6  B B B B B B   SMALL BINS

  RAW ANALOG VOLTS        PLOT OF RAW ANALOG VOLTS FOR EACH STELLAR         ANAMAX         GAINS,FILTERS
 ST1  ST2  ST3  ST4                                                                       ST1  ST2  ST3  ST4
1.04  .44  .38  .00     4    32     1                                    1.04 VOLTS     2,5  1,2  3,1  4,4
1.04  .46  .38  .00     4    32     1                                    1.04 VOLTS     2,5  1,2  3,1  4,4
1.08  .48  .40  .00     4    32     1                                    1.08 VOLTS     2,5  1,2  3,1  4,4
1.04  .48  .38  .00     4    32     1                                    1.04 VOLTS     2,5  1,2  3,1  4,4
1.06  .46  .38  .00     4    32     1                                    1.06 VOLTS     2,5  1,2  3,1  4,4
1.04  .46  .34  .00     4    32     1                                    1.04 VOLTS     2,5  1,2  3,1  4,4
                  VOLTS 0      1.00      2.00      3.00      4.00      5.00

  RAW DIGITAL COUNTS      PLOT OF RAW DIGITAL COUNTS FOR EACH STELLAR                    DIGITAL OVERFLOWS
 ST1  ST2  ST3  ST4                                                                      ST1  ST2  ST3  ST4
 182  105  120  185                   2  3          N *                 NIGHT             0    0    3    3
 181  104  116  181                   2  3           N*                 NIGHT             0    0    3    3
 181  107  113  175                    23        N 4 1                  NIGHT             0    0    3    3
 181  107   97  170                 3 2            4 N1                 NIGHT             0    0    3    3
 182  107   93  169                3  2            4  *                 NIGHT             0    0    3    3
 181  106   97  167                 3 2            4  *                 NIGHT             0    0    3    3
                 COUNTS 0       50       100      150      200      250

DUMP PROCESSED: WDSC
*************************************************************************************************************
```

Figure 3.3-4. DROOP Output (Frame): Frame of Reduced Stellar Photometer Data

Line A of Figure 3.3-4 gives the contact orbit number (normally an orbit or two after the observations were taken), the abbreviations of the ground station used, and the frame number. The frame number is the same as the sequence number arbitrarily assigned to that frame, with the first frame dumped during a ground station contact designated as '1.'

Line B lists information about the target object. Following the word 'star' is the vestigial 'S' followed by the star name (abbreviated), the right ascension (hours, minutes), the declination (degrees, minutes), the magnitude, the spectral type, the luminosity class, peculiarities (if any), the visual magnitude, B-V, U-B, spacecraft pitch and yaw (see the explanation of Figure 3.1-4 in Section 3.1 for further detail), the contact orbit number, the ground station initial, and the frame number (repeated from line A).

The lines labeled C list spacecraft and target position information. The first line indicates spacecraft day or night (in words), followed by the subsatellite range (latitude and longitude of subsatellite points during data collection), and the azimuth-zenith distance (in degrees) at the beginning and the end of the frame. These directions refer to the object relative to the subsatellite point. This is followed by the target object's longitude and latitude in both ecliptic and galactic coordinates (the second line), and on the last line, the spacecraft roll angle (degrees), the spectrometer slit position angle (degrees), the angular distance from the Sun (degrees), and the distance from the Sun in ecliptic longitude.

The lines labeled D contain miscellaneous command information, and, except for one item, they are not always needed for data reduction. The useful item is the time given in the lower right-hand corner (the end of the line beginning 'DS COM' Item Q). This date and time is the starting time of this frame of observations. This time is needed to compute the dark current using the fitted curve given on Figure 3.2-2 (using the start-time given above the right-hand corner of the plot on Figure 3.2-2, Item E).

The remaining tables and plots on the page list information as described below.

Column 1 of Tables E through H, under the heading INST, lists the instrument in use for this table (e.g., ST1 is Stellar Photometer 1, etc.). Column 2, under the heading GAIN, lists the exposure/gain setting for this table (e.g., 1=E1, 0.125-sec accumulation time, 10^{-6} ampere full-scale for the electrometer; 2=E2, 1.0-sec accumulation time, 10^{-7} ampere full-scale on the electrometer, etc.). Column 3, under the heading FILTER, gives the filter wheel position number and, in parentheses, the filter's effective wavelength or the word DARK or CAL. Column 4, under the heading AP, gives the aperture setting. A setting of L stands for large (10 arc-minutes in diameter), and a setting of S stands for small (2 arc-minutes in diameter). Column 5, under the heading (DATA - DK)/(CAL - DK), gives for each instrument the mean values and errors for the quantity (DATA - DK)/(CAL - DK) for analog, digitized analog, and digital data. Note that for dark data, the quantity is DK/(CAL - DK), and for calibration data the quantity is CAL - DK. Each quantity was derived from averaged values of the raw data and estimated error values given.

Column 6, under the heading DK/(CAL - DK), gives values of the ratio DK/(CAL - DK) computed using the dark current correction curve derived in Figure 3.2-2. Column 7, under the heading WT, gives a weighting factor, or quality factor, to be associated with these averages (6 denotes the best data, 0 the worst). This weighting factor is discussed in the description of the DROOP processing (see Figure 3.1-2d). Column 8, under the heading FLAGS, is actually a set of six columns (one for each observation made during this frame), containing flags showing the data quality and method of averaging for each individual data point. The flags are discussed in the description of DROOP processing (see Figure 3.1-2d). Column 9, under the heading DATA AVERAGING, indicates, in words, the type of data averaging used to derive the averages shown in Column 5.

Table I lists the raw analog voltages observed for each observation (in rows) by each instrument (in columns).

Plot J is a line-printer plot showing the values of the analog voltages observed by each of the four instruments as a function of time. The purpose of this plot is to summarize visually the variations in the observations.

Table K lists the maximum observed analog voltage for each set of observations (in rows).

Table L lists the exposure/gain-filter combinations for each observation within a frame. All rows within a column should be the same. If all rows within a column are not the same, that frame should be rejected.

Table M lists the raw digital counts observed for each observation (in rows) by each instrument (in columns).

Plot N is a line-printer plot showing the values of the raw digital counts observed for each instrument as a function of time. The purpose of this plot is to summarize visually the variations in the observations.

List O indicates whether the spacecraft was operating in spacecraft night during all of the observations. It should be a set of six rows, each row reading NIGHT.

Table P is a list of the estimated overflows of the digital accumulator for each observation (in rows) by each instrument (in columns).

3.4 DESCRIPTION OF DROOP TAPES WITH KNOWN ERRORS

On some of the DROOP tapes, all of the data reductions for one or more of the instruments are wrong. The cause of these problems can be either incorrect parameters input to the program or errors in DROOP's logic; we are aware of some tapes that are bad because of errors in the spacecraft ephemeris and others that are bad because of erroneous values of the mean CAL-DK used for the tape. Three groups of tapes that include examples of badly processed data are cataloged below.

Errors in the spacecraft ephemeris input to the program can result in badly processed data. These errors cause DROOP to compute incorrect subsatellite locations and, therefore, to misidentify those frames obtained during the spacecraft day or in the South Atlantic Geomagnetic Anomaly. In these tapes DROOP may have processed data that should have been discarded. (That it also discarded high quality data does not concern us here since those discarded measurements will not produce false results.) The tapes that are affected are 0992 through 1001 (in error by 10° or 2.8 minutes of time) and 1452 through 1471 (in error by 30° or 8.3 minutes of time).

On some tapes the mean value of the digital CAL-DK differs greatly from the value interpolated from other tapes. This discrepant value may be valid, but it is more likely to be an error caused by bad estimates of overflows, by bad dark fits, etc. The worst case appears on tapes 0202 and 0203 where the ST1 mean CAL-DK is about 670 counts/second, nearly 4 times the expected value. In this case the probable cause is an incorrect value of volts/overflow that, in turn, may be caused by a malfunction of the ST1 digital counter (Section 2.3). The tapes that may be in error are listed here.

Instrument	Tapes Affected
ST1	0022, 0023, 0202, 0203, 0762, 1332
ST2	0001
ST4	1601

The value of CAL-DK for ST4 may also be in error either on tapes 0001-0022 or on tapes 0023-0033. However, which of these sets is correct is merely an academic question since ST4, being badly misaligned at that time, detected no stars (Sections 2.3 and 4.8).

The third group of tapes includes tapes for which digitizing the mean value of the analog CAL-DK produces a number that differs significantly from the mean value of the digital CAL-DK. This discrepancy may indicate either that an incorrect value of volts/overflow was input to DROOP or that DROOP produced an incorrect value of the analog CAL-DK. An example of this problem occurs on DROOP tape 1132 where the mean value of the analog CAL-DK for ST3 is 1.57 volts. This number, together with the volts/overflow value of 0.10313, results in a predicted digital CAL-DK of 3897 counts/second. The correct mean value of the digital CAL-DK for this tape is 251.13 counts/second! In this case, the error arose because in one frame DROOP accepted electronic noise as a valid analog signal. To call attention to those tapes that <u>may</u> be affected by an erroneous value of analog CAL-DK or by an erroneous value of volts/overflow, we list here all tapes showing a discrepancy of 10 percent or more between the digitized mean of the analog CAL-DK and the mean of the digital CAL-DK.

Instrument	Tapes Affected
ST1	0022, 0023, 0033, 0113, 0151, 0211, 0212, 0271, 0281, 0321, 0331, 0692, 0721, 0751, 0752, 0771, 0872, 0914, 1051, 1072, 1081, 1101, 1112, 1282, 1321, 1381, 1382, 1401, 1452, 1491, 1492, 1532, 1571, 1613, 1701, 1784
ST2	0001, 0011, 0022-0033, 0042-0051, 0053-0102, 0112, 0113, 0121, 0141, 0152-0172, 0191-0212, 0222, 0223, 0242-0263, 0282-0302, 0312, 0313, 0323-0371, 0381-0441, 0451, 0452, 0481-0492, 0511-0541, 0551-0563, 0572-0582, 0592-0601, 0611, 0612, 0622, 0631, 0641, 0643, 0651, 0701, 0711, 0712, 0732, 0741, 0742, 0751, 0752, 0771, 0801, 0811, 0813-0832, 0841, 0861, 0881-0891, 0901-0922, 1051
ST3	0001-0021, 0032, 0033, 0181, 0183, 0193, 0201, 0223, 0252, 0253, 0271-0281, 0291, 0292, 0322, 0332, 0341, 0351, 0381, 0391, 0461, 0462, 0501, 0513, 0543, 0571, 0601, 0662, 0721, 0771, 0881, 0941, 1041, 1042, 1061, 1112, 1121, 1132, 1221, 1372, 1381, 1453, 1651, 1671, 1701, 1723

Users of analog data from these tapes should check the tape carefully to determine the cause of the discrepancy and, if necessary, derive a new mean value of the analog CAL-DK by hand. Users of digital data from these tapes should take extra care in ascertaining that DROOP has correctly computed the number of overflows.

4. DATA REDUCTION PROCEDURES

The following sections (Section 4.1 through 4.8) give a rigorous and detailed description of the procedures used to reduce OAO 2 stellar photometer data from the Wisconsin Experiment Package (WEP). Users of these data should read these sections to understand how the reduced data were derived, and to recognize improperly reduced data. It is strongly recommended that the user follow these procedures and reduce some of the data by hand, thereby either ascertaining that his results agree with those produced by the DROOP program or understanding why they do not. For a less rigorous summary of DROOP procedures, see Section 1.1.

First, the user must look through the catalogs of the photometer data (available from NSSDC either on magnetic tape as data set 68-110A-02G or on microfilm as data set 68-110A-02C) and find the observations listed which include the object of interest. The catalogs are ordered in three ways: (1) by the date and time of the observation, which is the order in which the data appear on magnetic tape and microfilm, (2) by increasing right ascension, and (3) by the spectral class of the observed object. All versions of the catalog reference observations by the week and part-of-week of OAO 2/WEP operation. This information (week xxx, part y) is needed to identify the reel of magnetic tape or roll of microfilm that contains the desired data. When ordering these data from NSSDC, please specify which format of photometer data is desired (magnetic tape or microfilm), and submit a list of week numbers/part numbers (for example, Number 1213 signifies Week 121, Part 3). Please refer to page 1-i of this report for the correct NSSDC address for requests.

With the data at hand on magnetic tape or microfilm, begin by turning to the star summary (see Figure 3.1-5). Then determine the contact(s) - there may be more than one - during which the object of interest was observed, and whether there were any data taken in Mode A (fifth column from the right, Item N on Figure 3.1-5). If no data were taken in Mode A, omit that particular contact and proceed to the next one. If data were taken in Mode A, list the contact number, the station identification, and the time of the first observation for that contact and proceed down the summary.

Next, turn to the frame summary (see Figure 3.1-6, described in Section 3.1) and determine if any frames in the contacts selected were taken in Mode A (Column E, Figure 3.1-6), during spacecraft night (Column F, Figure 3.1-6), and not while the spacecraft was within the South Atlantic Geomagnetic Anomaly (Column G, Figure 3.1-6).

These conditions are met if Columns E, F, and G all read AN. If these criteria are not met by any frames included in a contact, there are no valid, reducible photometer data in that contact. Check all of the contacts on the list in the same manner.

Now, it is necessary to note the volts/overflow and offsets (with their associated errors) for the different stellar photometers and different exposures (found on the first page of printout, table A, Figure 3.1-1, described in Section 3.1), and save this information for future reference. Along with these data, one should also note the averaged offsets (line B, Figure 3.1-1) and the dark current correction factors (line C, Figure 3.1-1).

From the page following the DROOP description, the CAL - DK values should be noted for future reference, along with the table of corrections for digital overflows (see Figure 3.1-3, Items B and C).

The summary page showing the observations in question should be referred to at this time (e.g., Figure 3.2-2), and the coefficients for the dark current fit (versus time) should be noted for future use, along with the time at t = 0 (see Figure 3.2-2).

Now, turn to the set of pages containing the data from each individual frame (see Figure 3.3-4 for an example).

These pages should be reduced one at a time. The following discussion, until the point at which all data are averaged together, will deal with the reduction of one frame of photometer data.

The first step is to determine the digitized-analog equivalent counts from the raw analog voltage, using the volts/overflow noted above. The procedures available for doing this are explained in Section 4.1.

Second, the estimates of the number of digital overflows must be confirmed (see Section 4.2 for procedures).

Next, having estimated the apparent digital count rate and corrected for overflows, an instrumental deadtime correction should be applied (see Section 4.3). NOTE: This correction has not been applied by the DROOP processing. However, the analog data do not require a deadtime correction.

Then, the six observations made during each frame (six observations for each instrument) must be averaged, with bad data, such as clearly inconsistent values, being purged in the process (see Section 4.4).

Next, the dark counts and dark current must be calculated from the dark count curve noted earlier, with the analog dark current being derived from the digital dark count, using the volts/overflow relationship described in Section 4.5. Using this information and the CAL - DK data noted earlier, the ratios of DK/(CAL - DK) can be derived for both analog and digital data (but not for digitized-analog data). The DK/(CAL - DK) values should agree with those given on the data page (e.g., Figure 3.3-4, Items E-H, Column 6). Note that these values are derived at Exposure/gain 2 (E2, accumulation time of 1.0 sec, analog full scale = 10^{-7} ampere).

The analog, digitized-analog, and digital data must then also be converted to Exposure/gain 2 (E2), removing various instrumental biases in the process (see Section 4.6).

The (DATA - DK)/(CAL - DK) ratios are averaged for each telescope/filter combination, and this average ratio is then converted to its equivalent OAO magnitude. Note that filter degradation has <u>not</u> been included in DROOP processing. The resultant data are OAO magnitudes, normalized to the 3320-A filter photometer, but <u>uncorrected</u> for sky background. This OAO magnitude should be corrected for filter degradation and sky background (if necessary). Note that sky background observations are treated in the same way as observations of stars.

Finally, all results taken with a given stellar photometer and using a given filter are combined to yield the results given on the summary of observations.

4.1 DIGITIZING ANALOG DATA

This section is concerned with deriving the digitized-analog data, which in turn are used in Section 4.2 to confirm that the number of digital accumulator overflows has been properly estimated. Analog data are digitized by applying the equation

$$\text{Digitized-analog} = (\text{ANALOG} - \text{OFFSET}) \times 256/(\text{volts/overflow}), \qquad (4.1\text{-}1)$$

where the volts/overflow value is that applicable to that photometer at the exposure/gain specified.

While Equation (4.1-1) is straightforward, the derivation of the appropriate offset and volts/overflow is not. Any of several approaches may be used.

The approach adopted by the University of Wisconsin (the principal investigators of this experiment) was to use the offset from the table of offsets (e.g., table A, Figure 3.1-1), or, lacking that, from the nearest calculated offset-volts/overflow combination (see the table of derived values, Figure 3.1-1, table A, described in Section 3.1). Where the desired exposure/gain was straddled, for example where the value for E2 was desired and the values of E1 and E3 were given, the value given for the higher gain was used, since this value is less likely to contain deadtime errors. Similarly, the volts/overflow value needed was taken from the table (table A, Figure 3.1-1) or derived from the nearest listed value by using the conversion factor of 1.25, in the form

$$(\text{Volts/overflow})_{E_x} = (\text{volts/overflow})_{E_y} \times 1.25^{(E_x - E_y)}. \qquad (4.1\text{-}2)$$

An alternative approach is to use weighted mean values of the offset and volts/overflow, normalized to a particular exposure/gain, such as E2. Then, the mean offset is used throughout, and the required volts/overflow value is derived from the mean volts/overflow, using the 1.25 factor. In the following example, the data were normalized to E2:

$$(\text{Volts/overflow})_{E_x} = (\text{Mean volts/overflow})_{E2} \times 1.25^{(E_x - 2)}. \qquad (4.1\text{-}3)$$

The weighted means (normalized to Exposure/gain 2) are derived using Equations 4.1-4 through 4.1-9. Note that no entries are used for volts/overflow or offsets where none exists in the table. Any summations in the following equations are to be made over all the values for a given stellar photometer.

The mean volts/overflow at Exposure/gain 2 is given by

$$< V/O >_{E2} = \frac{1}{\sum\limits_i WTV[i]} \times \sum_i WTV[i] \times (V/O)[i] \times 1.25^{2-E[i]}, \tag{4.1-4}$$

and the corresponding uncertainty

$$< \delta\left(V/O\right) >_{E2} = \frac{1}{\sum\limits_i WTV[i]} \times \sqrt{\sum_i WTV[i] \times \delta(V/O)[i] \times 1.25^{2-E[i]} \quad ^{2}}, \tag{4.1-5}$$

where the weighting terms are defined as follows:

$$WTV[i] = \frac{V/O[i]}{\delta V/O[i]}, \tag{4.1-6}$$

$V/O[i]$ = volts/overflow at exposure $E[i]$,

$\delta V/O[i]$ = error in volts/overflow at exposure $E[i]$.

The mean offset is defined as

$$< offset > = \frac{1}{\sum\limits_i WTO[i]} \times \sum_i WTO[i] \times offset\ [i], \tag{4.1-7}$$

where the corresponding uncertainty is

$$< \delta\text{-offset} > = \frac{1}{\sum\limits_i WTO[i]} \times \sqrt{\sum_i WTO[i] \times \delta\text{-offset}\ [i] \quad ^{2}}, \tag{4.1-8}$$

and the weighting terms are defined as

$$WTO[i] = \frac{\text{offset } [i]}{\delta\text{-offset } [i]} , \tag{4.1-9}$$

offset [i] = offset at exposure E[i],

δ-offset [i] = error in offset at exposure E[i].

Frequently a 'local' offset and volts/overflow are needed. These local values can be derived from within a given set of observations. The manner in which these values can be derived is described below.

The necessary conditions for derivation are (1) that at least two observations at different gains through any one filter of the photometer in question are available, (2) that the true total digital counts are known for all of these observations, (3) that the lowest analog reading is greater than 0.00 volt, (4) that the highest analog reading is less than 5.04 volts, and (5) that stellar flux and dark noise are expected to be nearly constant for both observations.

One can solve for the offset by using the following equations:

$$\text{Volts}(i) = \text{signal}(i) - \text{Offset} , \tag{4.1-10}$$

and

$$\text{Volts}(j) = \text{signal}(j) - \text{Offset} , \tag{4.1-11}$$

and

$$\text{signal}(j) = \text{signal}(i) \times 10^{(j-i)}, \tag{4.1-12}$$

where volts(i) and volts(j) are the averaged voltages for Exposure/gains i and j, signal(i) and signal(j) are the observed signals for Exposure/gains i and j, and the offsets remain the same throughout. Further, if the total digital counts ($=n_j + 256\ m_j$) are known for these observations and the deadtime error is <u>not</u> significant, then one can determine the volts/overflow, since

$$(\text{Volts/overflow})_{E_i} = 256 \times [\text{volts}(i)\text{-offset}(j)]/\text{counts}(i) \tag{4.1-13}$$

and

$$(\text{Volts/overflow})_{E_j} = 256 \times [\text{volts}(j)\text{-offset}(j)]/\text{counts}(j). \tag{4.1-14}$$

4.2 ESTIMATING DIGITAL OVERFLOWS

Estimating the number of digital accumulator overflows requires both the raw digital data (given in Figure 3.3-4, Item M) and the derived digitized-analog signal. If the digitized-analog and the digital channels tracked each other perfectly, the number of overflows would be given by the expression

$$\text{Overflows} = ([\text{DIG-ANA}] - \text{DIGITAL})/256. \qquad (4.2\text{-}1)$$

Since they do not track perfectly, however, a suitable alternative is to take the ratio derived in Equation (4.2-1), noting that it is always greater than or equal to zero, add 0.5 to it, and truncate the fractional part. At large count rates, where the deadtime correction is large, the number of overflows cannot be determined by using the linearly derived volts/overflow.

It is particularly important that one be careful when DROOP gives a single number of overflows for all six observations of one instrument, and the digital counts read numbers like '2 253 3 5 250 251.' In this case something is amiss, and the user himself must determine the correct number of overflows. In this example the number of overflows associated with the observations of 2, 3, and 5 counts is clearly one more than the number of overflows associated with the observations of 253, 250, and 251. In the above case the number of counts were very near to forcing another overflow, and the analog resolution did not unambiguously solve the problem.

In the case of data from Stellar Photometer 4, the analog channel is derived from model spectra, and all digital data should be treated with caution.

If the analog channel is saturated, one can look for another observation made at a lower gain (during the same observing sequence) and extrapolate a value for the unsaturated voltage, since the voltage gain varies by a factor of 10 from one exposure/gain setting to the next. If the data are not saturated and one cannot obtain reasonably consistent results, the volts/overflow and offset values may not be correct. In this case, local offset and volts/overflow values may have to be derived (see Section 4.1) and used.

When the lowest gain gives a saturated analog signal, one may be faced with nonlinearities in the counter (see Section 4.3). This problem usually concerns ST1 F3, although for the brightest stars ST1 F1, ST1 F4, ST3 F2, and sometimes ST3 F1 can be affected.

If, at the lowest gain, one can confidently determine the number of overflows, then that digital total may be used to predict the total counts. Given this, one can determine the number of overflows for larger integration times, since an increase in exposure from E_i to E_{i+1} will result in an increase of counts by approximately a factor of 8.

C-2

As a last resort, one may be forced to accept an ambiguity for the time being, and resolve this ambiguity only after deriving magnitudes from other filters and then varying the number of overflows until the data are consistent.

If the analog channel is saturated, DROOP usually assigns an incorrect number of overflows even if it has correctly estimated the overflows for lower-gain observations with the same filter.

A simple method of checking whether overflows have been properly applied is to plot raw analog volts against the digital DATA/(CAL-DK) for a single gain (see Figure 4.3-1). Data from more than one orbit and object may be used. These data points should fall on a straight line if digital deadtime effects are insignificant, or on a smooth curve if digital deadtime effects are important. After corrections for digital deadtime (see Section 4.3), all the data points should lie on a straight line which passes through the 'offset' at zero counts.

4.3 INSTRUMENT DEADTIME CORRECTIONS

The basic photon detectors employed at the focus of the stellar photometers were photomultipliers. However, the photomultipliers and their attendant electronics required a finite amount of time to recover from detecting every photon. The result of this dead time during recovery is that the apparent count rate is less than the true count rate. This effect can be corrected using the following equation:

$$\text{Counts(true)} = A + (B \times \text{counts(apparent)}) + (C \times \text{counts(apparent)}^2) + (D \times \text{counts(apparent)}^3). \quad (4.3\text{-}1)$$

Equation (4.3-1) applies only to Stellar Photometer 1 at Exposure/gain 1 for counts higher than 600, and to Stellar Photometer 3 at Exposure/gain 2 for counts between 1200 and 8000. For these two cases only, the following values apply:

$A = -7.5$ (ST1 E1) or 34.135 (ST3 E2),
$B = 1.12022$ (ST1 E1) or 0.915744 (ST3 E2),
$C = -0.0003556$ (ST1 E1) or 4.04533×10^{-5} (ST3 E2), and
$D = 2.94 \times 10^{-7}$ (ST1 E1) or 5.05502×10^{-9} (ST3 E2).

The fits listed above match the data to within a root-mean-square error of 1.8 percent for ST1 E1, and to within 2.9 percent for ST3 E2. These corrections are shown in Figures 4.3-1 and 4.3-2.

Note that these deadtime corrections are count-rate dependent, and hence, in theory, can be applied to other exposures as well. For example, ST1 E2 can be corrected using the formula

$$\text{Counts(apparent)}_{E1} = 0.125 \times \text{counts(apparent)}_{E2}. \quad (4.3\text{-}2)$$

In general, count rates can be transformed using

$$\text{Counts(apparent)}_{Ex} = \text{Counts(apparent)}_{Ey} \times 8^{x-y}. \quad (4.3\text{-}3)$$

The transformations given by Equations (4.3-2) and (4.3-3) merely serve to convert raw counts to the count rate (in counts/time interval) appropriate for applying the count-rate correction. Other transformations can be deduced from Table 2.2-1.

Note that this deadtime correction is not applied as a part of the DROOP procedure and must be applied by hand.

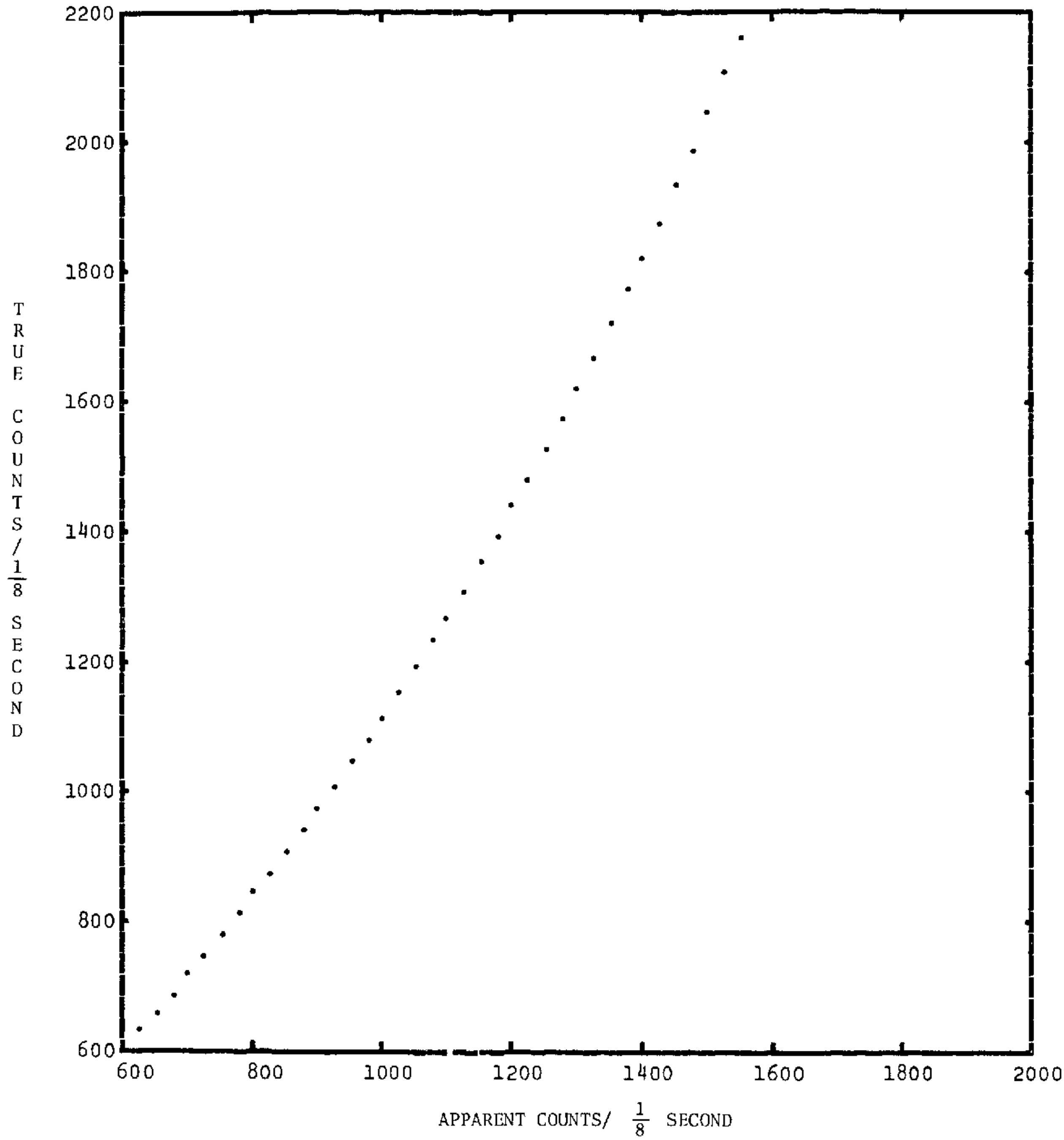


Figure 4.3-1. Deadtime Correction for Stellar Photometer 1 at Exposure/gain 1

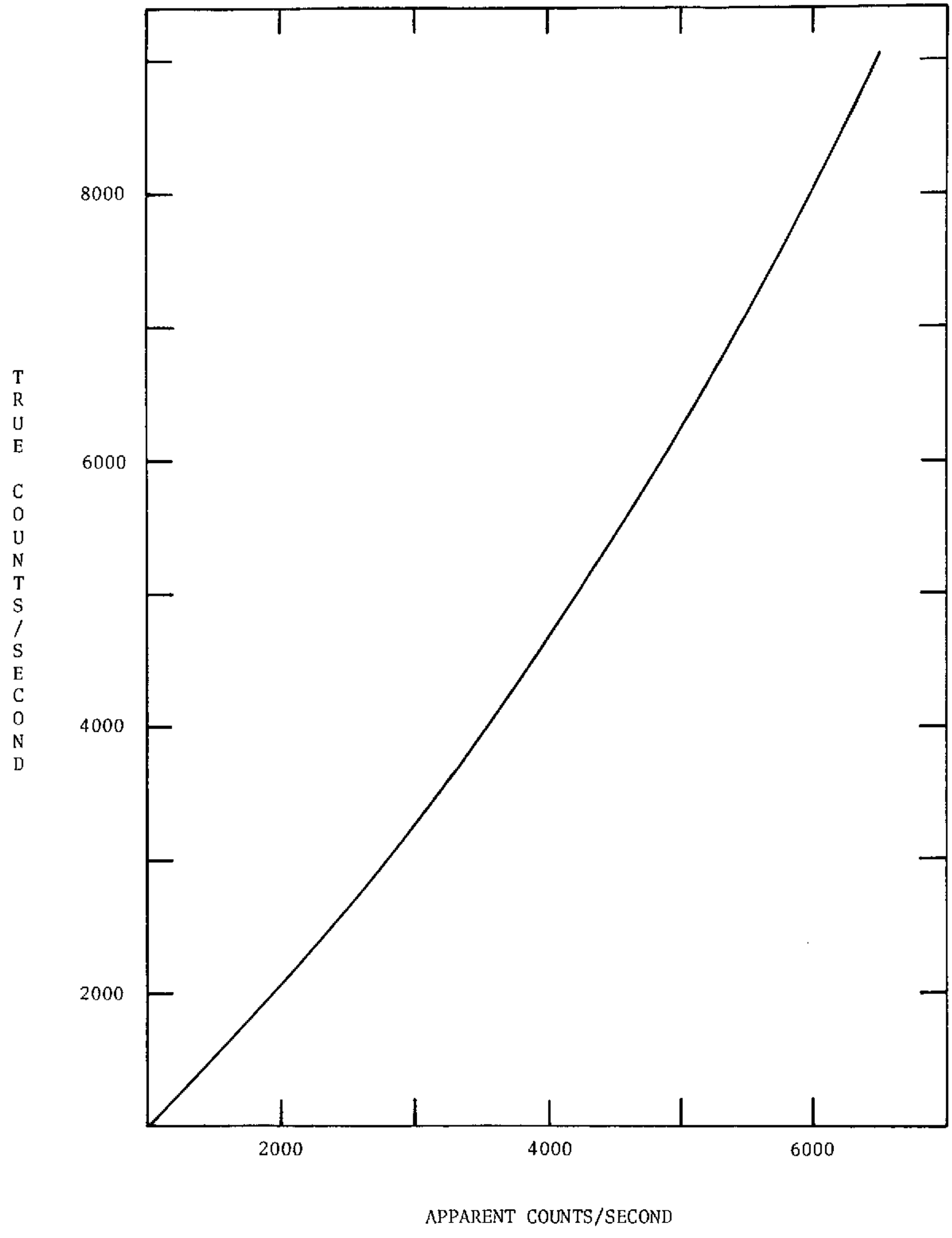


Figure 4.3-2. Deadtime Correction for Stellar Photometer 3 at Exposure/gain 2

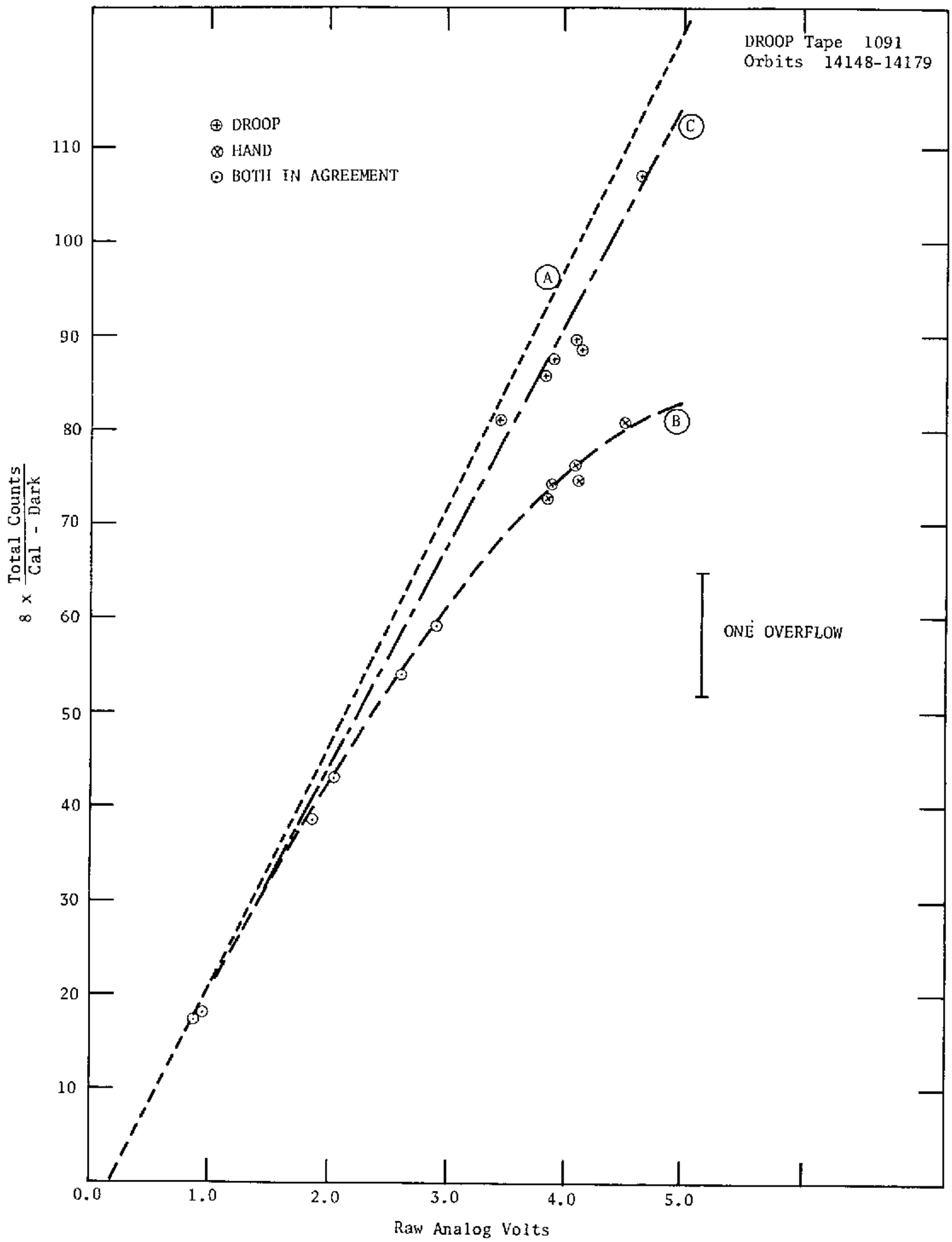


Figure 4.3-3. ST1 E1 Analog-Digital Relationship

Because the volts/overflow value is derived from a linear least-squares fit to nonlinear data, the number of overflows calculated by DROOP for measurements for which the deadtime error is large will be wrong. In fact, DROOP will produce a number for the total digital counts that will be closer to the digital counts plus deadtime correction than to the true total digital counts. Figure 4.3-3 shows a comparison between DROOP-reduced ST1 E1 data and hand-reduced ST1 E1 data for DROOP Tape 1091. In neither case has a deadtime correction been applied. In this figure, Curve A represents a hand-drawn approximation to the linear region of the volts/overflow relationship, Curve B represents the true relationship between analog and digital signals, and Curve C represents the volts/overflow relationship used by DROOP. Curve A has been extended into the nonlinear region to provide a comparison with Curves B and C. Note that the hand-reduced data are well fit by Curve B in both count rates and slope. The DROOP-reduced data lie along Curve C (with some scatter), but the slope determined from the data does not agree with the slope of Curve C. It is expected that deadtime corrections applied to the hand-reduced data will lie close to Curve A. DROOP has added one or two extra overflows to some of the data to force them to satisfy a linear volts/overflow relationship. These points (with too many overflows) lie close to the values they would have if the correct number of overflows plus the deadtime correction were applied to the raw digital counts. If a deadtime correction was applied to the DROOP digital data without first correcting for the false overflows, a very large error would be created.

Figure 4.3-4 shows the approximate V-magnitude, as a function of spectral type, at which DROOP begins to add false overflows to ST1 digital data to force a linear relationship. A star that lies below any one of these curves in the V-magnitude/spectral-type plane will probably have false overflows added to the observation by the filter to which that curve applies. This diagram is not exact. It is intended as a guide, not a rule. One must not assume that the reduction of an observation of a star which lies above one or all of these curves is free from error.

Similar diagrams and statements could be produced for Stellar Photometer 3.

The analog data offer a possible alternative to the process of overflow determination and deadtime correction, since no deadtime corrections are required for them. Usually the digital data are preferred to the analog because of the greater precision attainable with digital data. The analog data are less precise because the quantum of measurement (0.02 volt) was large (equal to 0.4 percent of the possible range of the measurement). However, if the number of overflows cannot be determined or if the deadtime correction is very large (as it is for ST3 F2 for such stars as αCMa, βCen, or γVel), one might consider

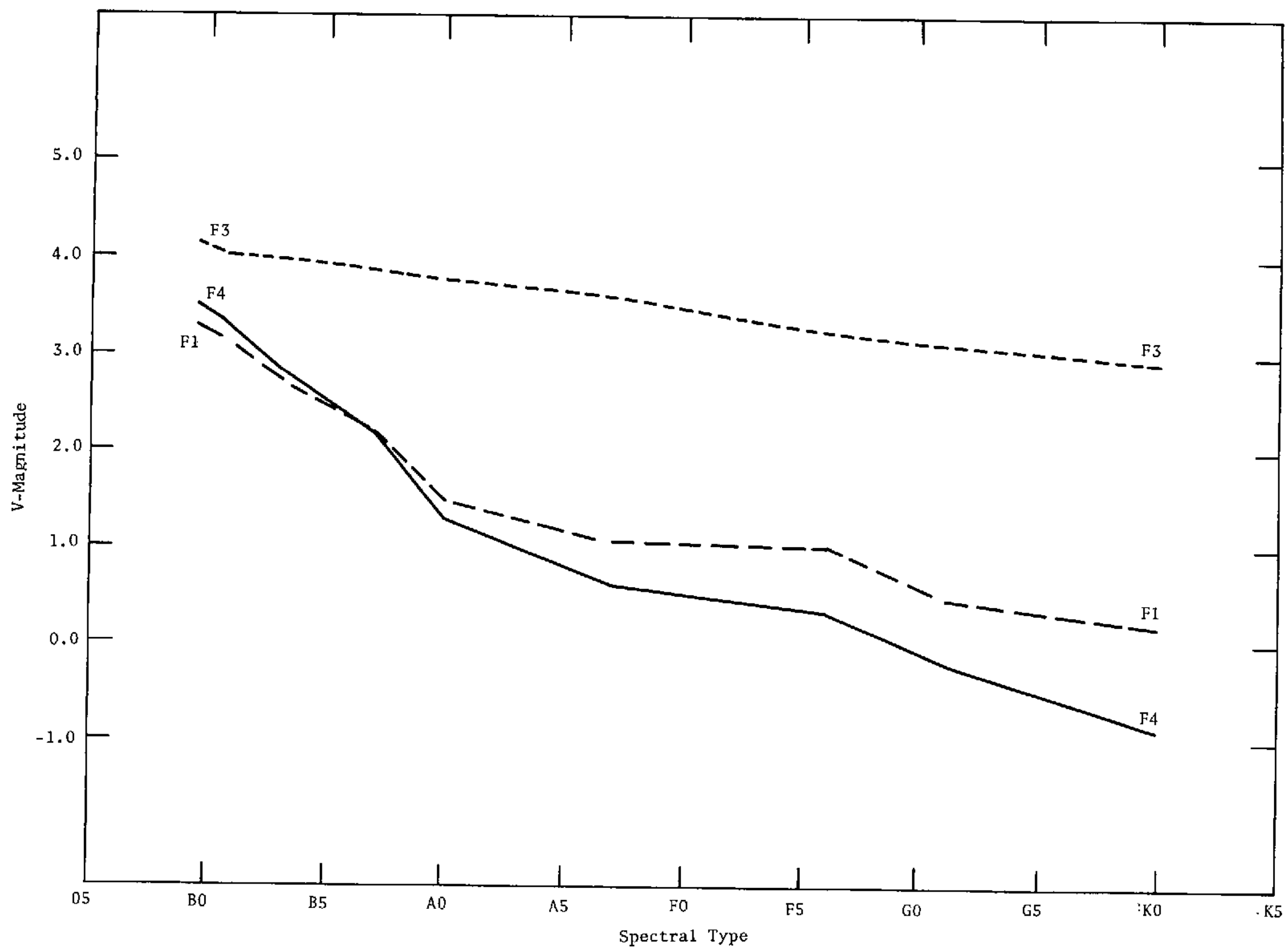


Figure 4.3-4. Approximate V-Magnitudes At Which DROOP Starts To Produce Erroneous Overflows for ST1

using the analog data. For ST1, only the large size of the measurement quantum will introduce new errors. However, for ST3 a possible new source of error is introduced because the analog equivalent for ST3, CAL-DK, must be derived from the digital value of CAL-DK and the value of volts/overflow. Since, as we have stated before, the volts/overflow value may have a systematic error due to the attempted fitting of non-linear data with a linear function, this process can introduce new errors into the final values of R'_λ. Some indication of the error present in volts/overflow can be observed by comparing the volts/overflow values determined at different gains after they have been converted to E2 equivalents after multiplication by appropriate power of 1.25 (see Section 4.1). The probable errors in the analog reduction should then be compared to the probable errors in the digital reduction for each individual case, and the result with the lowest probable error should be adopted.

4.4. FRAME-AVERAGED DATA

The DROOP software averages the analog and digital data, using slightly different methods for each. Note: should the dark current vary significantly during any frame, the dark current should be calculated for each of the six observations and subtracted from these observations prior to averaging (see Section 4.5). This procedure is not done by DROOP.

The raw analog data (table I, Figure 3.3-4) are first adjusted by subtracting the dark current and the offset voltages from them. Then each column is averaged by dropping the individual data points into bins of specified size (see the description at the beginning of each DROOP tape, or Figure 3.1-4), and then including in the final average only those data in the 10 bins nearest the most populous bin. The normal bin size is determined as the larger of 0.04 volt or a percentage of the raw mean voltage (default value is 2 percent). This size of bin is referred to as a 'small bin'; if averaging is not possible, the bin size is doubled (and labeled a 'large bin') and an average attempted. If averaging in large bins fails, the data are rejected. Note that the bins are used only to eliminate bad data and that all averages are obtained using the original data points and not the average of bin values.

The digital data were averaged after adding the correction for the number of overflows:

$$\text{Counts(apparent)} = \text{counts(digital)} + (256 \times \text{overflows}). \qquad (4.4\text{-}1)$$

The digital counts referred to are the raw digital counts given in columns in table M of Figure 3.3-4. The overflows are given in Figure 3.3-4, table P, one overflow value for each of the six raw digital results. Note that the overflow estimates should be confirmed (see Section 4.2). The data are then averaged (see above procedure: bin size is the larger of two counts or two percent of the raw mean); the filter biases are subtracted; and one half-count is subtracted to compensate for the additional count registered when the prescaler was half-full. Note also the DROOP description at the beginning of each DROOP tape, or Figure 3.1-5.

Note that for both the analog and digital averages, the procedure used is indicated (see Figure 3.3-4, Column 9), and even the disposition of the individual points is shown (see Figure 3.3-4, Column 8).

An alternative averaging procedure is to calculate the mean and the standard deviation (sigma, σ) and, on the next cycle through the data, exclude all data points lying outside the bounds of the mean $\pm$ 1.5 σ. This procedure may be followed more than once, the limits becoming narrower with each iteration as the amount of data decreases. Care should be exercised, however, that too many points are not excluded, since then the average may become meaningless.

4.5. DARK COUNT/DARK CURRENT CORRECTIONS

The first step in determining the dark counts or dark current to be subtracted from the combined object and dark current data (normal raw data) is to calculate the dark counts using the expression

$$\text{Dark-counts} = ((\text{COLUMN-T**2}) \times \text{time}^2) + (\text{COLUMN-T} \times \text{time}) + \text{CONST}, \quad (4.5\text{-}1)$$

where COLUMNS-T,T**2, and CONST refer to columns shown in table C of Figure 3.2-2 (the curve fit for dark data given on the page following the object summaries), and time is the observing time in minutes since T_0. T_0 is given on the right-hand side above the plot in Figure 3.2-2. This equation yields the dark counts for a given detector at Exposure/gain 2. The corresponding analog dark current can be found using the equation

$$\text{Dark current} = (\text{dark counts}) \times (V/O)_{E2} / 256, \quad (4.5\text{-}2)$$

again evaluated at Exposure/gain 2.

The dark count versus time curve was derived in the following manner. Raw data from one orbit were used, even through they may have included observations of several stars. Mode C and Mode A 'DO-cycle' data were excluded, although data taken in the South Atlantic Geomagnetic Anomaly, in daylight and after a star had set, were used if all four photometers had dark slides and their frames bracketed a normal photometry sequence. Data were excluded if the analog channel of a dark slide was saturated (only the affected photometer was excluded). Using the data derived above, dark count versus time fits were calculated, using one of the two methods described below.

If the first and last frames had dark-slide data on all four photometers, individual curve fits were made for each photometer. A second-order least squares fit was attempted, but if the resulting error was too large for any one photometer, that photometer was given a 'collective' fit, using the procedure described below.

For a 'collective' fit, all dark-slide data (except ST2 E1, ST3 E1, ST3 E2, ST3 E3, and all ST4 data) were converted to equivalent Photometer-1 values, using transformations derived separately for each data tape. If these transformations were not supplied to DROOP, the following default transformations, based on early data, were used:

$$ST2 = (0.16 \times ST1) - 0.56 \quad (4.5\text{-}3a)$$

$$ST3 = (0.0112 \times ST1) + 0.7906 \quad (4.5\text{-}3b)$$

$$ST4 = (0.0032 \times ST1) + 0.7988 \quad (4.5\text{-}3c)$$

A second-order least squares fit was attempted. When the error was too large, a first-order least squares fit was attempted. When this error was also too large, the data were averaged. Where data were missing for one photometer, the transformation was used to fill it in. Where no dark-slide data were available for any photometer, the DARK value was set equal to 0.0. Default values adopted for CAL - DK were 165, 68, 252, and 143 counts.

Should the dark current change significantly during a given frame of six exposures, the dark current and dark counts should be calculated for each individual observation. The individual observations all start together at intervals determined by the longest exposure/gain time being used (e.g., if E1, E2, E3, and E4 were being used by ST1, ST2, ST3, and ST4, respectively, all observations would commence at 64-second (E4) intervals). Next both the analog voltages and digital counts should be corrected by subtracting the dark values from the individual measurements. Only then should the six observations made during the particular frame be averaged. This procedure is necessary only on rare occasions.

For ST3, the first and second lines of a DARK frame following a CAL frame or a filter measurement of a very bright star frequently will be erroneously large. If a second-order least squares fit to the dark count rate was adopted by DROOP, that fit will be influenced by these erroneous DARK measurements and will probably be bad. If the dark count rate is large and "important" compared to the object count rate, a new time-dependent dark count curve should be derived (by computer or by hand) with the erroneous data excluded.

4.6 DETERMINING THE SIGNAL-TO-CALIBRATION RATIOS

This section is divided into three parts: one dealing with analog data, one dealing with digitized-analog data, and one dealing with digital data.

The analog data are treated in the following manner. First, the columns of analog data are averaged. (See Section 4.4 for a discussion of averaging techniques.) Then the offset voltages are subtracted from the averaged analog voltages. (See Section 4.1 for a discussion of voltage offsets.) These are normally found on the first page of a DROOP output, such as that shown in Figure 3.1-1. Thirdly, the resulting differences are normalized to Exposure/gain 2, using the expression

$$\mathrm{ANALOG}_{E2} = \mathrm{ANALOG}_{E_x} \times 10^{2-x}. \tag{4.6-1}$$

Then the calculated dark current is subtracted from the normalized differences (for a discussion of dark current calculations, see Section 4.5). Finally, the value of CAL - DK voltage, averaged over the entire tape, must be divided into the above result. CAL - DK values are listed on the tables giving calibration readings for the tape, e.g., Item B in Figure 3.1-3, and on the object summary page, e.g., Item D in Figure 3.1-1. This division is not made with calibration data, since the data desired are the calibration signals in volts, not the ratios of individual calibration signals to the average calibration signal. The resulting ratios are given on the frame pages (e.g., tables E through H, Column 5, Figure 3.3-4). Note that DROOP normalized the calibration signal to the intensity of the radioactive source at the time of launch. Thus, calibration signals derived from individual frames (rather than read from the corrected DROOP output) must be multiplied by exp (5.27×10^{-6} x orbit number) to be properly normalized.

The procedure for reducing digitized-analog data follows: First, the analog data are converted to digital data using the expression

$$\text{DIG-ANA} = (\text{ANALOG} - \text{OFFSET}) \times 256/(\text{volts/overflow}), \tag{4.6-2}$$

in which the offset and the volts/overflow correspond to the telescope and exposure/gain in question. Next, the data are averaged using the procedures discussed in Section 4.4. Then, the data are normalized to Exposure/gain 2 with the equation

$$(\text{DIG-ANA})_{E2} = (\text{DIG-ANA})_{E_x} \times 8^{2-x}. \tag{4.6-3}$$

Then, the digital dark counts calculated from the dark curve are subtracted from the data. If the data are not calibration data, the digital value of CAL - DK is divided into the above difference. The resulting ratios or calibration counts are given on the frame pages (e.g., tables E through H, Column 5, Figure 3.3-4).

The procedure for reducing digital data follows. First, the apparent digital counts are reconstructed according to the formula

$$\text{Apparent digital counts} = \text{raw digital counts} + (256 \times \text{overflows}). \qquad (4.6\text{-}4)$$

Then, the apparent digital counts are converted to true digital counts by applying the deadtime corrections (see Section 4.3). These deadtime corrections are not applied by DROOP.

Then, the true digital counts are averaged using the techniques of Section 4.4. One half-count is then subtracted from each of these averages to correct for the additional count added to the accumulator when the prescaler is over one-half full at the end of an accumulation period. Then, for Stellar Photometers 3 and 4 only, bias counts arising from the fluorescence induced by the strontium^{90} calibration source must be subtracted. These bias counts are listed in Table 1.1-1 and on the DROOP output. Note that Table 1.1-1 lists the bias counts for the filters and the dark slides separately, while the DROOP listing gives only bias values for the filters and has the dark slide values subtracted from the filter values.

The averaged, corrected digital data are then converted to Exposure/gain 2 using the equation

$$\text{Corrected-digital}_{E2} = \text{corrected-digital}_{E_x} \times 8^{2-x}. \qquad (4.6\text{-}5)$$

The calibration dark counts are subtracted, and the difference, providing that the data are not calibration data, is divided by the digital value, CAL - DK. The resulting ratios or calibration counts are given on the frame pages (e.g., tables E through H, Column 5, Figure 3.3-4).

4.7 CONVERSION OF OAO MAGNITUDES AND SUBSEQUENT CORRECTIONS

The DROOP software yields preliminary OAO magnitudes according to the following definition:

$$\text{OAO-MAG} = -2.5 \log(\text{DIGITAL}) - C_\lambda,$$

where $$\text{DIGITAL} = (\text{averaged digital data} - \text{DK})/(\text{CAL} - \text{DK}), \quad (4.7\text{-}1)$$

and $$C_\lambda = -2.5 \log(\text{DELTA}).$$

The expression "log(DELTA)" is tabulated at the beginning of each DROOP output tape. C_λ is tabulated on Table 4.7-1. All data are converted to Exposure/gain 2. The quantity DELTA is the reciprocal of the sensitivity of each filter combination relative to ST1 F1 (3317 A) as derived from a comparison of B3V stars with model atmospheres (T_E = 17,000° K, and Log(g) = 4).

A revised absolute calibration of the OAO magnitude system is presented next. This absolute calibration is based on rocket observations of α Virginis, η Ursae Majoris, and α Leonis. The fundamental radiation standard is the synchrotron radiation from the University of Wisconsin Physical Science Laboratory storage ring.

The convention adopted for the revised OAO magnitude system, M, is that the magnitude for any filter is equal to the visual magnitude, V, if the energy-per-unit-wavelength interval is constant. The energy corresponding to V = 0.00 is 3.61×10^{-9} ergs cm^{-2} sec^{-1} A^{-1} (Code, in Problems of Calibration of Absolute Magnitudes and Temperatures of Stars, edited by B. Hauck and B. E. Westerlund, p. 131, D. Reidel Publishing Co., Dordrecht, Holland, 1973). Thus, M = 0.00 for any OAO filter corresponds to an integral effective intensity of 3.61×10^{-9} ergs cm^{-2} sec^{-1} A^{-1} at the constant-energy wavelength

$$\langle\lambda_0\rangle = \left(\int \lambda S(\lambda)\,d\lambda\right) \Big/ \int S(\lambda)\,d\lambda \quad , \qquad (4.7\text{-}2)$$

where the integrals are smoothed over 100-angstrom intervals.

In addition to listing values of C_λ ($C_\lambda = -2.5 \log(\text{DELTA})$, where log(DELTA) is given by the DROOP software), Table 4.7-1 lists the differences between the OAO-MAG given by the DROOP software and the revised magnitude, M. This difference is called δ, is listed in Column 4, and is added to the OAO-MAG's to convert them to their equivalent M_λ's. Column 5 of Table 4.7-1 lists values of K_λ defined by

$$M = K_\lambda - 2.5 \log(\text{DIGITAL}), \qquad (4.7\text{-}3)$$

so that M can be determined directly from the DIGITAL data.

Table 4.7-1

Absolute and Relative Calibration Corrections

Photometer		λ_o (angstroms)	C_λ (magnitude)	δ (magnitude)	K_λ (magnitude)	$\frac{F_\lambda}{\text{Counts}_{E2}}$ erg cm^{-2} sec^{-1} Å^{-1} count^{-1}
ST1	F3	4250	+1.70	6.18	7.88	1.55 E-14
ST1	F1	3320	0.00	6.27	6.27	6.79 E-14
ST1	F4	2985	-0.31	6.36	6.05	8.34 E-14
ST2	F2	2965	-0.11	6.44	6.33	1.56 E-13
ST2	F5	2380	-1.15	6.53	5.38	3.75 E-13
ST2	F1	2035	-1.80	6.46	4.66	7.28 E-13
ST3	F2	2460	-2.04	6.39	4.35	2.61 E-13
ST3	F1	1915	-4.11	6.38	2.27	1.78 E-12
ST3	F5	1680	-6.17	6.18	0.01	1.42 E-11
ST4	F1	1555	-5.29	6.53	1.24	8.08 E-12
ST4	F3	1430	-5.54	6.51	0.97	1.04 E-11
ST4	F4	1330	-6.62	6.44	-0.19	3.02 E-11

LEGEND:

λ_o = constant-energy wavelength of filter.

C_λ = -2.5 log(DELTA); these are values algebraically added by DROOP to the value -2.5 log(DIGITAL) to produce OAO-MAG.

δ = factor to be added to OAO-MAG (output by DROOP) to obtain new magnitude M_λ.

K_λ = C_λ + δ; this converts -2.5 log(DIGITAL) directly to new magnitude system M_λ, bypassing DROOP processing.

$F_\lambda/\text{counts}_{E2}$ = energy corresponding to single count at Exposure/gain 2.

Column 6 of Table 4.7-1 lists the value of energy corresponding to one digital count at Exposure/gain 2. (Note that this refers to a raw count and not to the digital value from (DIG - DK)/(CAL - DK).)

Table 4.7-2 presents representative magnitudes, M, for early-type stars. The magnitudes represent the energy distribution for main-sequence stars for V = $0^{m}_{.}00$ and no interstellar extinction; i.e., E = 0.00. These representative values are based on the mean of approximately 10 little-reddened stars in each spectral class and provide a basis for comparison with reductions of other stars on the OAO-M_λ system.

The meaning of wideband or heterochromatic photometry measurements is relatively free from ambiguity for early-type stars. The magnitudes represent the energy averaged over a bandpass on the order of 100 angstroms, centered at λ_0. For later-type stars the effect of line blanketing introduces some ambiguity into the interpretation of wideband energy measurements. This ambiguity should be kept in mind when interpreting the results obtained for A, F, G, and K stars.

The data must be corrected for filter degradation (see Section 2.1). The correction to be applied is

$$M(\text{corrected at } t) = M(\text{observed during orbit } t) - \Delta M(t),$$

where values of $\Delta M(t)$ are given in Figures 2.1-5 through 2.1-16. Note that DROOP software does not apply any filter degradation corrections.

Finally, the effects of sky background must be dealt with. The sky background has not been removed from any stellar observations. Sky background measurements were made, however, and were treated in the same way as any other object by the DROOP software. To remove the sky background, a sky background observation near the object in question (best found by looking at the sort by right ascension/declination in the DROOP catalog) must be obtained and the following equation used:

$$M(\text{background-corrected}) = -2.5 \log \left\{ (10^{-0.4 \times M(\text{obj})}) - (10^{-0.4 \times M(\text{sky})}) \right\}, \qquad (4.7\text{-}4)$$

where M equals the OAO-MAG or the revised magnitude.

Note that sky background corrections are significant for many objects, particularly for observations made with ST1 F3 and ST4 F4, and that DROOP software does not make these corrections.

Remember also that any other objects within the field of view of the photometers must be removed, using the same techniques as described above for removing the sky background.

Table 4.7-2

Average M_λ for V = 0.00, E = 0.00 Main - Sequence Stars

Photom	λ_o	Spectral Type	07	B3
S1 F3	4250		-1.21	-0.94
S1 F1	3320		-1.94	-1.25
S1 F4	2985		-2.35	-1.53
S2 F2	2965		-2.39	-1.56
S2 F5	2380		-3.16	-2.09
S2 F1	2035		-3.61	-2.47
S3 F2	2460		-3.02	-2.02
S3 F1	1915		-3.83	-2.69
S3 F5	1680		-4.14	-2.96
S4 F1	1555		-4.44	-3.22
S4 F3	1430		-4.80	-3.40
S4 F4	1330		-4.99	-3.50

4.8 FILTER MAPPING AND ASSOCIATED PROBLEMS WITH TELESCOPE ALIGNMENT AND SPACECRAFT POINTING

Users who need to do a detailed subtraction of field stars or who are attempting to interpret the observations of extended sources will need to know the projected location of each instrument's field of view on the sky and the probable errors in that location. The most significant problems with misalignment and nonuniform filter response have already been mentioned in this users guide (Section 2.3). In this section we trace quantitatively the history of the relative alignment of the instruments and the optical axis of the observatory. Then we shall indicate how the misalignment data can be used in the celestial coordinate system. Finally, we shall present spatial maps of each filter.

Events that are pertinent to the history of instrumental alignment are measurements of the relative alignment of the instruments, recollimations of the instruments, and realignments of the star trackers (the primary pointing control system for experimentation). The relative alignment of the instruments was measured on 24 occasions. These measurements are the basis for the present section. However, the accuracy of these measurements is limited by the pointing accuracy of the spacecraft. Furthermore, because of the distribution of these measurements in time they are not sufficient to specify the location of the field of view during the entire 4 years of operations. Each stellar photometer was equipped with a mechanism for stepping the field stop assembly laterally in the focal plane to permit in-flight recollimation. The size of each step was 1 arc-minute. A knowledge of all of the recollimation commands executed by the instruments, together with the measured alignment errors, should permit an accurate alignment history to be compiled <u>if no other factors affected the instrumental pointing</u>. We are not certain that we have located the records of all recollimation commands. Moreover, the instrumental pointing was controlled by the spacecraft pointing system. Therefore, the occasions when changes were made to the misalignment constants for the star trackers represent possible discontinuities in the alignment of the instruments. (The misalignment constants for the star trackers were used to calculate the angles at which the star trackers were to be pointed to make the spacecraft assume a desired attitude.) The pointing errors of the spacecraft are not well determined; they may depend upon the attitude of the spacecraft, the temperatures of the different components of the spacecraft, and the individual star trackers used.

Table 4.8-1 presents the alignment history of the instruments. Column 1 gives the interval in orbit numbers during which a given alignment appears to be valid. Columns 2-5 give the locations of the center of the field of view of each photometer in the spacecraft coordinate system. These locations are in terms of pitch offset (ΔP) and yaw offset

Table 4.8-1

The Alignment of the Stellar Photometers

Orbit Interval	Coordinates of the Center of the Field of View (in arc-minutes of pitch and yaw)				Notes
	ST1	ST2	ST3	ST4	
0- 384	(-0.4, -0.5)	(1.4, 4.1)	(-0.6, 3.6)	YAW>+5	2
384- 595	(-0.4, -0.5)	(1.4, 2.1)	(-0.6, 3.6)	YAW>+5	2
595- 794	(-1.9, 1.6)	YAW<-5	(-1.0, 3.4)	(-1.6, 4.2)	2
794- 808	(-1.9, 1.6)	(-0.9, 1.4)	(-1.0, 3.4)	(-1.6, 4.2)	2
808- 822?	(-1.9, 1.6)	(-0.9, 1.4)	(2.0, 3.2)	(1.4, 4.2)	2
822- 835	(-2.1, 2.3)	(-3.1, 0.3)	(1.0, 3.2)	(1.1, 4.2)	3
835- 837	(-2.6, 2.5)	(-2.6, 0.5)	(1.0, 3.2)	(-0.4, 4.4)	4
837- 839	(-2.6, 0.5)	(-2.6, -3.5)	(1.0, 3.2)	(-0.4, 4.4)	4
839- 1160	(-2.6, 0.5)	(-2.6, -2.5)	(1.0, 3.2)	(-0.4, 4.4)	4
1160- 1204	(-2.6, 0.5)	(-2.6, -2.5)	(1.0, 3.2)	(-0.4, 4.4)	4
1204- 1231	(-2.6, 0.5)	(-2.6, -2.5)	(-2.0, 3.2)	(-0.4, 4.4)	4
1231- 1403	(-2.6, 0.5)	(-2.6, -2.5)	(-2.0, 3.2)	(-3.4, 4.4)	4
1403- 1596	(-2.6, 0.6)	(-2.8, -1.4)	(-1.6, 1.1)	(-1.8, 8.1):	4
1596- 1598	(-2.6, 0.6)	(-2.8, -1.4)	(-0.6, 1.1)	(-4.8, 8.1):	4
1598- 1599	(-2.6, 0.6)	(-2.8, -1.4)	(-0.6, 1.1)	(-1.8, 8.1):	4
1599- 1611	(-2.6, 0.6)	(-2.8, -1.4)	(0.4, 1.1)	(-0.8, 8.1):	4
1611- 1612	(-2.6, 0.6)	(-2.8, -1.4)	(0.4, -2.9)	(-0.8, 2.1)	4
1612- 1624	(-2.6, 0.6)	(-2.8, -1.4)	(0.4, 0.1)	(-0.8, 4.1)	4
1624- 1991	(-2.6, 0.6)	(-2.8, -1.4)	(0.4, 0.1)	(-0.8, 2.1)	4
1991- 3086	(-2.6, 0.6)	(-2.8, -1.4)	(0.4, 0.1)	(-0.8, 2.1)	3
3086- 3630	(-0.8, 0.8)	(-1.6, -0.2)	(1.6, 1.0)	(0.3, 2.1)	3
3630- 4210	(-0.8, 0.8)	(-1.6, -0.2)	(1.6, 1.0)	(0.3, 2.1)	4
4210- 5527	(0.9, 1.3)	(0.4, 0.0)	(3.4, 1.4)	(1.5, 2.9)	4
5527- 7730	(0.9, 1.3)	(0.4, 0.0)	(3.4, 1.4)	(1.5, 2.9)	4
7730- 8195	(0.9, 1.3)	(0.4, 0.0)	(3.4, 1.4)	(1.5, 2.9)	2
8195- 8220	(0.9, 1.3)	(0.4, 0.0)	(4.4, 1.4)	(1.5, 2.9)	2
8220- 8272	(0.9, 1.3)	(0.4, 0.0)	(4.4, 1.4)	(1.5, 2.9)	4

Table 4.8-1 (concluded)

Orbit Interval	Coordinates of the Center of the Field of View (in arc-minutes of pitch and yaw)				Notes
	ST1	ST2	ST3	ST4	
8272- 8299	(0.9, 1.3)	(0.4, 0.0)	(7.6, 1.4)	(1.5, 2.9)	2
8299-10392	(0.9, 1.3)	(0.4, 0.0)	(0.2, 1.4)	(1.5, 2.9)	2
10392-10822	(0.9, 1.3)	(0.4, 0.0)	(0.2, 1.4)	(1.5, 2.9)	4
10822-12117	(1.8, 0.8)	(1.1, -0.4)	(0.5, 0.8)	(2.8, 2.5)	1
12117-12259	(1.8, 0.8)	(1.1, -0.4)	(0.5, 0.8)	(2.8, 2.5)	1
12259-12656	(1.8, 0.8)	(1.1, -0.4)	(0.5, 0.8)	(2.8, 2.5)	1
12656-12670	(1.8, 0.8)	(1.1, -0.4)	(0.5, 0.8)	(2.8, 0.5)	1
12670-22000	(1.8, 0.8)	(1.1, -0.4)	(0.5, 0.8)	(1.8, 0.5)	1

Notes for Table 4.8-1:

1. Based on an average of offsets measured under control of the bore-sighted star tracker. These positions are most accurately determined, but they cannot be accurately applied to observations obtained under gimbaled star tracker control because of pointing errors. The orbit intervals for which these measurements are given are somewhat arbitrarily chosen because the first measurements used in these averages were obtained at orbit 8955, but the bore-sighted star tracker was not routinely used during observations until after orbit 10822. Some of the coordinates are estimated from collimation commands.

2. Based on an average of offsets measured under control of the gimbaled star trackers. Some of the coordinates are estimated from collimation commands.

3. Based on a single measurement under control of the gimbaled star trackers.

4. Estimated. These coordinates are the least accurately determined.

(ΔY) and are presented as vectors (ΔP, ΔY). The sign and magnitude of each offset are determined by the sign and magnitude of spacecraft motion away from the nominal pointing that is required to center the target image in each instrument. Column 6 refers to a note giving a brief indication of how the alignment data were obtained.

It is clear from the discussion above that the accuracy of the alignment data varies. Those measurements obtained with the use of the bore-sighted star tracker are most accurate since that star tracker could maintain the spacecraft pointing within a few arc-seconds and could be offset in units of 15 arc-seconds. In reflection of this accuracy, the average distance of the individual measurements from the mean (under bore-sighted star tracker control) is only 0.2 arc-minute. However, only the brightest stars could be observed under bore-sighted star tracker control; stars with $V>3.2$ usually were observed under gimbaled star tracker control. In intervals having more than one alignment test under gimbaled star tracker control, the average distance of the individual measurements from the mean is 0.7 arc-minute. These results are not satisfactory between orbit 1160 and orbit 1991 because several recollimations of instruments and realignments of star trackers occurred in that interval without adequate measurements of the relative alignment of the instruments. The large changes in offsets that apparently occur at orbit 1403 give one indication of errors in this interval. Another indication is the large offset derived for ST4 between orbit 1403 and orbit 1611. This derived offset is definitely shown to be wrong by observations of stars obtained between orbit 1596 and orbit 1611. However, in view of the limited data available it would be difficult to derive better results. Fortunately, relatively few data are involved since the OAO 2 was used by the Smithsonian Astrophysical Observatory during most of this time period.

The rate with which a star disappears from the field of view of a photometer during measurements of alignment suggests that the image diameter is about 1.5 arc-minutes. Data taken with the 2 arc-minute diameter apertures suggest an image size of the same order.

To use the stellar photometer offsets, it is necessary to go from the spacecraft-fixed (pitch, yaw) -system to the celestial coordinate system. This transformation can be carried out with the use of the roll angle (Section 3.2). If one were looking towards the sky with right ascension increasing towards the left, then the roll angle is measured clockwise from the +declination direction to the -pitch direction. The +yaw direction is given by the roll angle minus 90°. In general spherical triangles are required for the transformation, but for the small angular distances involved in the instrumental fields of view a simple rotation of coordinates is adequate. Let the roll angle be ρ, the target coordinates be (α_0,δ_0), and the center of the field of view be given by $(\Delta P,\Delta Y)$

in spacecraft offset and by (α_f, δ_f) in celestial coordinates. Then

$$(\alpha_f - \alpha_o) \cos \delta_o = -(\Delta P \sin \rho + \Delta Y \cos \rho) \qquad [4.8\text{-}1]$$

and

$$(\delta_f - \delta_o) = \Delta P \cos \rho - \Delta Y \sin \rho \ . \qquad [4.8\text{-}2]$$

This transformation locates the center of the field of view in the sky if there are no spacecraft pointing errors. Objects within 4.2 arc-minutes of this location will be included completely; objects out to 5.8 arc-minutes will be included partially.

The spacecraft pointing errors are the major source of uncertainty in measuring the instrumental alignments and in applying them to the observations. The repeated measurements of instrumental alignment suggest that pointing errors of 0.5 to 0.7 arc-minutes are likely under gimbaled star tracker control during the first 10,000 orbits of operation. In the interval between orbit 3630 and orbit 4210 the operations crews frequently reported errors of up to 3 arc-minutes from the star trackers. After the failure of star tracker 1 at orbit 10822, data from scanning spectrometer 2 show that pointing errors greater than 1.5 arc-minutes were not uncommon during gimbaled star tracker control. Pointing errors of about 5 arc-minutes occurred during three intervals given in Table 2.3-1 when λ Scorpii (Guide Star 42) was used as a guide star. In this case, it is possible that the errors were caused by the star tracker guiding on the center of light of λ Scorpii and ν Scorpii. We cannot predict the magnitude or direction of pointing error from a knowledge of the star tracker configuration in use during an observation. A pointing error is almost as likely to move the image of the target star into the field of view of a poorly aligned photometer as it is to move it out of the field of view.

The response of the stellar photometers has spatial variations due to variations in transmission by the filters, by the Fabry lenses, and by the faceplates of the photomultiplier, and to variations in photocathode sensitivity. Maps of these variations (called "filter maps" despite the potential multiplicity of causes) are shown in Figures 4.8-1 through 4.8-4. These maps were constructed from observations obtained while moving the stellar image about the field of view by offsetting the bore-sighted star tracker in 1 arc-minute increments in pitch and yaw. The number given at each offset position represents the response at that position in percentage difference from the response at the zero offset position (except for ST3 F5). The zero offset position is indicated by the dash marks below and to the right of each map. A circle for each map gives the approximate position of the edge of the field of view at the time of the mapping. Points close to the edge may be vignetted by the field stop. Standard deviations were estimated from the photo-event rate and the uncertainty introduced by the prescaler (Section 1.1). Most of these maps were constructed from observations of the bright early-type stars, θ Eridani and α Gruis, obtained during the last year of OAO 2 operations. The following comments apply to individual cases:

ST1 F3 This mapping, carried out on α Serpentis, is incomplete because of a loss of stability.

ST1 F4 An apparent pinhole is located in the region between (0.0, -4.0) and (-2.0, -1.0). It shows up most strongly in red light. The response to α Serpentis (spectral type K2 III) at the pinhole is 70 percent greater than elsewhere on that filter.

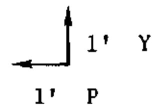
ST2 The filters of ST2 are not adequately mapped. The data represented here were obtained during observations of early-type stars during the first 2 years of observations.

ST3 F5 These data have been normalized to the relatively uniform region at the lower left. The increase in response towards the upper right is greater for θ Eridani (spectral type A3) than it is for α Gruis (spectral type B5). This map represents an average of data from both stars.

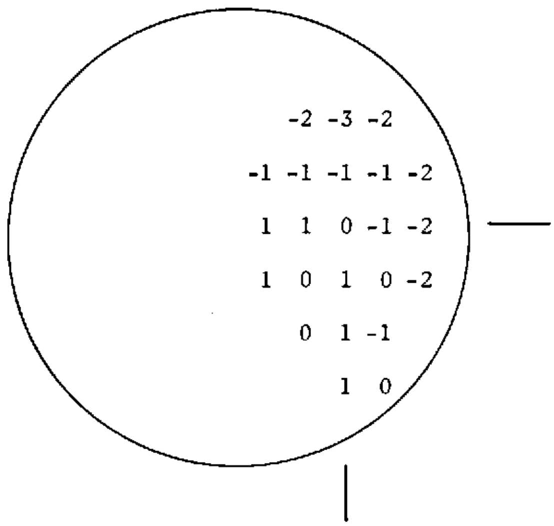
ST4 This instrument did not have a Fabry lens to focus the image on the photocathode.

The recollimation of the field stop does not change the location of the filter wheel assembly or the photomultiplier tube relative to the optical axis of the observatory. The star's image will not be moved about the filter maps; only the edge of the field of view will be moved. Therefore, the response of a given photometer/filter combination to a given star will not be changed by a recollimation except by vignetting or occultation of the star by the field stop. However, a change of the pointing direction of the instrument relative to the sky will move the star's image to a different location in the filter maps. Such a change in pointing direction could be brought about by purposeful offsetting of the instrument away from the stellar position, by realignments of the star trackers, or simply by pointing errors. Furthermore, the filters probably have some freedom for lateral movement in the filter wheel. Possible movement of the filters is a source of inaccuracy in the maps in Figures 4.8-1 through 4.8-4, as well as a complication in applying those maps to other observations. The use of these maps to correct the response of the instrument to stars is, in most cases, unwarranted in view of the uncertainties introduced by pointing errors and filter movement. However, they do help to assess the quality of an observation.

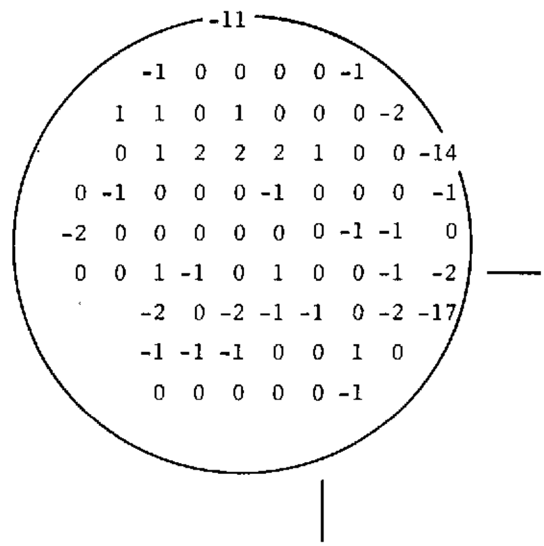
Figure 4.8-1. Stellar 1 Filter Maps



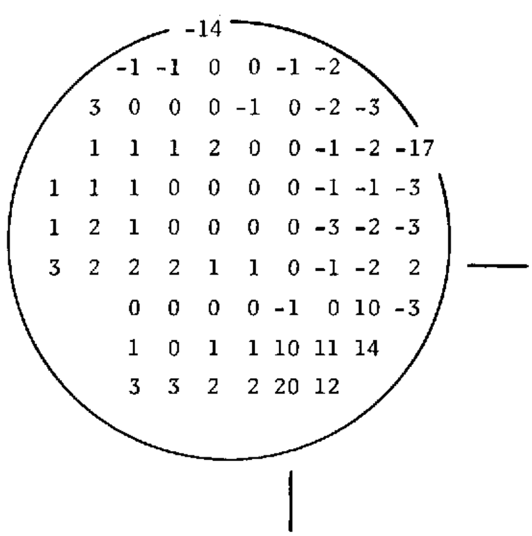
ST1 F3 4250 Å



ST1 F1 3320 Å



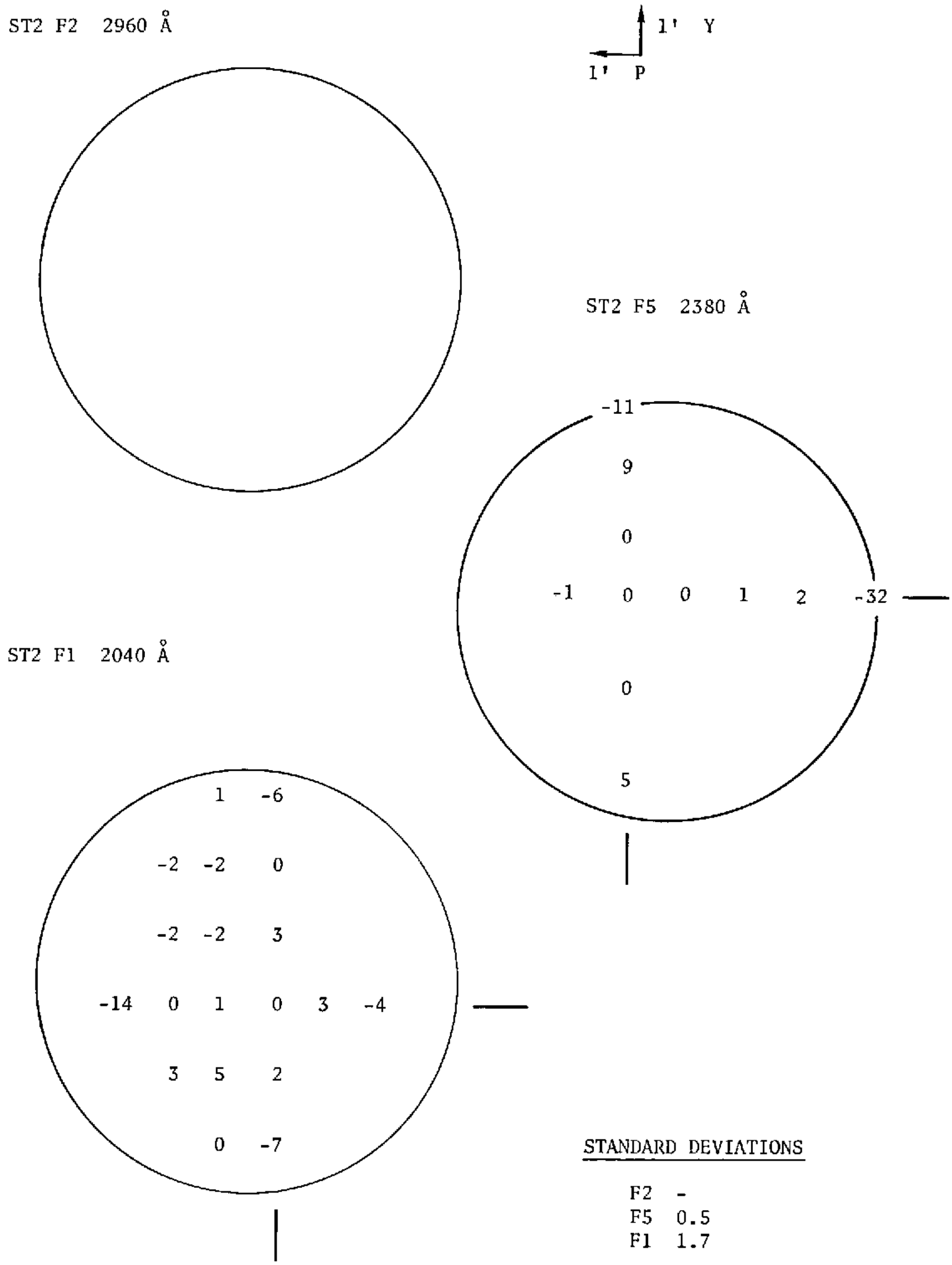
ST1 F4 2980 Å



STANDARD DEVIATIONS

F3 0.6
F1 0.5
F4 0.6

Figure 4.8-2. Stellar 2 Filter Maps



STANDARD DEVIATIONS

F2 -
F5 0.5
F1 1.7

Figure 4.8-3. Stellar 3 Filter Maps

1' Y

1' P

ST3 F2 2460 Å

			-13	0	0	5	-31		
	-48	1	1	2	3	4	5	6	
-36	1	2	2	3	3	4	5	5	
0	1	0	1	1	2	3	4	3	
0	0	0	0	0	1	1	1	1	2
0	0	0	0	0	0	0	0	0	2
0	-2	-1	-2	-1	-1	0	0	0	1
-2	-3	-3	-2	0	-1	0	0	4	
	-2	-2	-1	0	0	0	0	-2	
		-4	0	0	0				

ST3 F1 1910 Å

			-2	4	6	9	-30		
		4	5	5	5	6	6	4	
	4	5	5	2	3	3	2	2	
2	1	1	0	1	1	1	2	4	
0	0	-1	0	0	0	1	0	1	1
0	0	1	1	0	0	0	0	0	0
-2	-1	-1	-2	-2	-1	-1	-1	-1	1
-3	-1	-1	-1	-1	-2	0	0	4	
	-3	-2	-3	-1	-2	-2	0	-4	
		-6	-6	-3	-3				

ST3 F5 1680 Å

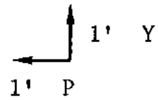
			26	50	60	77	-18		
		23	41	74	69	56	47	16	
	6	45	55	66	80	99	79	55	
6	10	11	29	79	92	102	104	62	
3	3	4	33	44	69	68	86	61	45
6	6	3	17	33	62	65	57	65	50
0	2	1	0	0	1	55	45	77	75
-2	-2	1	3	1	9	23	36	52	
	2	4	5	8	10	22	26	43	
		13	12	11	14				

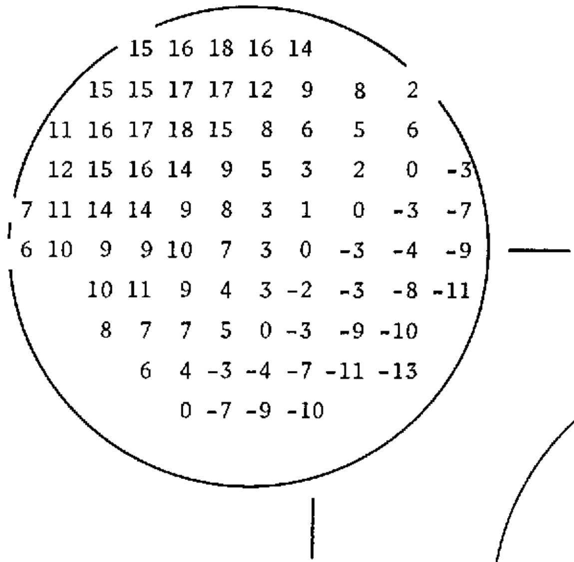
STANDARD DEVIATIONS

F2	0.6
F1	0.8
F5	1.6

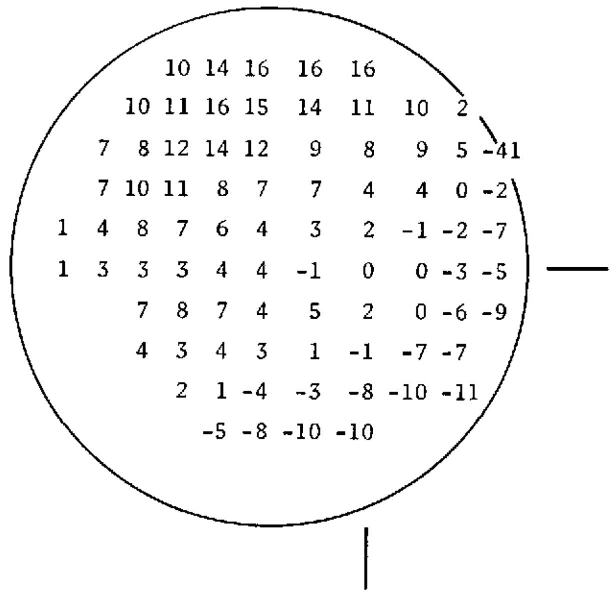
Figure 4.8-4. Stellar 4 Filter Maps

ST4 F1 1550 Å

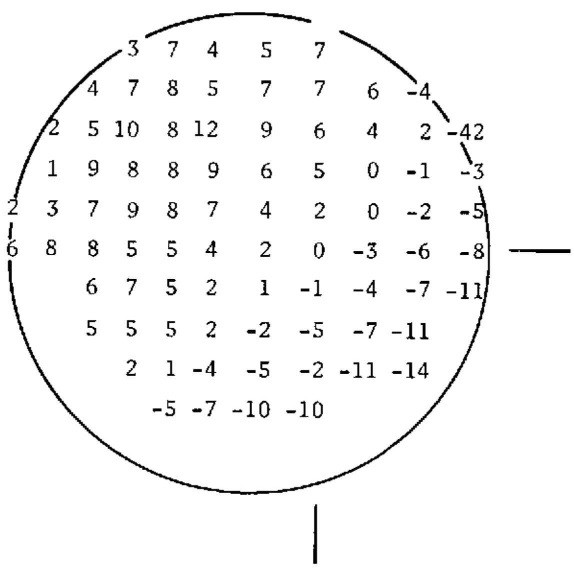




ST4 F3 1430 Å



ST4 F4 1330 Å



STANDARD DEVIATIONS

F1	0.9
F3	0.9
F4	1.6

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