An Improved Time Correction for the FES Calibration

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Abstract

A new analysis has been performed of the time-dependent changes in the FES photometric calibration, using calibration star data obtained from 1978 through the end of 1988. The sensitivity seems to have been constant until late 1980 to mid 1981, then started decreasing linearly with time. The FES overlap and underlap modes changed in a similar fashion, but the time that the sensitivity decrease started and the rate at which the FES is losing sensitivity differ somewhat. These parameters have been determined from FES data for calibration stars obtained from 1978 through 1988. The FES in overlap mode started decreasing in sensitivity at about 1981.65 at a rate of 4.13 percent per year. In underlap mode the FES started decreasing on about 1980.60 at a rate of 2.91 percent per year.

I. Introduction

IUE Guest Observers frequently make use of the FES counts obtained in conjunction with their observations to estimate the brightness of their objects. With the appropriate calibration, it is possible to transform these counts to an equivalent V magnitude with an accuracy of several hundredths of a magnitude.

Several FES calibrations have been published during the lifetime of IUE. An article by Holm and Rice (1981) discusses the various calibration efforts through 1981. Calibrations by Holm and Crabb (1979) and by Stickland (1980) were in use at GSFC and at VILSPA, respectively. Later it was recognized that the FES is losing sensitivity with time (Barylak, Wasatonic, and Imhoff 1985). Subsequently the IUE Three Agencies agreed to derive a new, improved FES calibration which could be used jointly at both IUE Observatories. A preliminary new calibration was derived by Imhoff and Wasatonic (1986). This calibration includes a time-correction term and a more complex color correction. However it was quickly realized that the second-order polynomial used for the time correction was diverging from the actual sensitivity change. We have therefore embarked on a new analysis of the time correction for the FES calibration. Once this analysis is completed, it is expected that the other terms in the calibration will also be rederived.

II. Data Used in the Analysis

The analysis was performed on FES data obtained at the current reference point for several calibration stars over time. (The FES reference point is the location in the FES field-of-view at which the target is centered prior to being placed in the aperture for an exposure; see discussions of the FES and aperture plate in Sonneborn et al., 1987.) These stars were chosen because they have been observed frequently and are bright enough to yield a reasonable number of counts. Data for five overlap and three underlap stars were

collected from 1978 through the end of November 1988.

The data were taken from the IUE Merged Log, including both NASA and VILSPA measurements. The log lists the FES counts as recorded by the Telescope Operator during the acquisition of the star. The average counts for the star at a point near the reference point (though not neccesarily exactly at the reference point) are noted. For these relatively bright stars no sky subtraction was performed.

Some checks were made of the quality of the data. Data points which were noticeably discrepent were checked against the original observing records.

Table 1
Calibration Star Data Used in the Analysis

Star	FES Mode	Number of Points
HD 34816	Underlap	195
HD 120315	Underlap	485
HD 3360	Underlap	349
	Total	1039
HD 60753	Overlap	1141
BD+75 325	Overlap	740
BD+33 2642	Overlap	303
BD+28 4211	Overlap	788
HD 93521	Overlap	550
	Total	3522

The data for each star were normalized to the average counts over an initial period of time when the FES sensitivity does not seem to be changing. This period was chosen to be 1978.0 to 1980.0, i.e. the first two years of data. The normalization permitted the merging of data for several stars. This procedure produced a single, merged file of data for the overlap stars and another merged file of data for the underlap stars.

Figure 1 depicts the normalized FES counts for both overlap (dots) and underlap (x) stars. One can see that the sensitivity changes for the two FES tracking modes, though similar, do not follow quite the same relationship, most noticeably in the last several years. Separate analyses were therefore performed for the two sets of stars.

The initial fits which were attempted with the data involved exponential terms, since it was felt that such functions are most likely to describe the physical changes in the detector that might account for the sensitivity changes. However, the attempts to fit the relationship between time and normalized FES counts with an inverse exponential function were found to be inadequate. A pair of straight lines seemed to fit the data better. In fact, the FES sensitivity appears to be nearly unchanged until around 1981, after which the sensitivity decreased linearly with time.

III. The New Analysis

Techniques and software were developed for deriving the best fits simultaneously for two linear functions. The starting date for the large decrease in sensitivity, called the "split date", must be determined as well as the parameters (slope and intercept) of the individual functions. This is done by performing various fits to the data for a range of split dates. The criteria which were defined for the best solution are:

(1) the second line intersects the first line at the split date,
(2) the scatter (i.e. sigma) of the data around the first line is minimized, and
(3) the scatter around the second line is minimized.

The first criterion was considered to have the highest weight. The scatter criteria were less sensitive and were applied less stringently.

The expectation that there was essentially no sensitivity change for the early years was tested. The formal value of the slope for the first three years was slightly negative (-0.5 percent per year) for overlap stars but slightly positive (+0.4 percent per year) for underlap. We feel that this difference was probably not significant, and a slope of 0 is a reasonable assumption. The assumption of no early sensitivity change produces errors not significantly different from those obtained by the formal fits. Thus a slope of 0 for the time prior to the split date was included in the subsequent analysis.

The next parameter which must be determined is the split date. The best solutions for the overlap and underlap stars, following the criteria described above, yield different split dates. Figure 2 shows the values of the normalized FES counts at the split date and the scatter for the two fits plotted against a range of assumed split dates for the overlap stars. In each plot, x denotes quantities for the fit before the split date, and + indicates quantities for the fit after the split date. In the lower plot, one can see that the mean of FES counts before the split date stays about 1.0 until late in 1981. This implies that after this date, smaller FES readings are being included which depress the mean; i.e. the straight line fit with slope = 0 is no longer appropriate. The second curve represents the FES counts at the split date predicted for a line fitted to the data after the split date. If the split date is chosen to be too early, the predicted FES counts at the split date are too high; if too late, too low. Criterion (1) is met, that is the value of the FES counts at the split date equals 1.0, at 1981.65. The upper plot shows the scatter around the fitted curves for the fits computed for the various split dates. The minimum in the scatter for the fitted line before the split date is in early 1980, while the minimum for after the split date is around mid-1981. The minima are broad and reasonably consistent with the split date. Thus a split date of 1981.65 was adopted for the overlap stars.

Figure 3 shows the same plots and quantities for the underlap stars. The criterion of continuity indicates a split date of 1980.60. The minima for the scatter in the fitted lines are not as clear in this case, but are not inconsistent with this choice of the split date. Thus this date was adopted for the underlap stars.

It seems odd that there should be two different split dates for underlap and

overlap stars. These measurements are performed at virtually the same location in the FES, so it is unclear why the sensitivity would start to decrease in one mode before the other. It is known that the FES overlap measurements have been affected in recent years by the development of a "fatigue spot", a small area right at the reference point of reduced sensitivity (Barylak, Wasatonic, and Imhoff 1985). However if this were the cause of the different initial epochs of sensitivity decrease, one would expect the overlap stars to be affected first, and this is not the case. On the other hand, the development of the fatigue spot, especially if it occurred earlier or later than the general decrease in the sensitivity, could cause some peculiar effects on the linear fit.

Inspection of the data in Figure 1 shows that the sensitivity changes are clearly different between the overlap and underlap stars. The slope of the sensitivity decrease is certainly greater for the overlap stars, most noticably after 1983. This is probably due to the gradual development of the fatigue splot. However it is difficult to tell if the difference in the split dates is significant. It was decided to retain the differing split dates, rather than force them to be the same, to insure the consistency of the final analysis.

An initial linear fit was performed for the merged data for the underlap stars using a split date of 1980.60. For the overlap stars, the fit was performed using a split date of 1981.65. The FES counts, previously normalized to the mean of the data for the first two years, were renormalized to the mean of the data before the split date. We note also that the analysis was done with time in the units of "days since 1978". This avoided difficulties in handling leap years. However the final results given below are listed in units of years, since this effect is quite small. The initial fit was then used to identify points which fall more than 3 sigma from the line. These points were then excluded for the final linear fit.

The data and final fitted lines for the overlap stars are shown in Figure 4. A similar plot for the underlap stars is given in Figure 5. The sensitivity decline was found to be 2.91 percent per year for the underlap stars and 4.13 percent per year for overlap stars. As noted above, the greater sensitivity decrease for the overlap stars may be due to the development of the fatigue spot. If so, then the fatigue spot currently decreases the FES sensitivity by about 10 percent beyond the general sensitivity loss of about 20 percent. The scatter around the fits for the underlap stars is about 3 percent (sigma), while for the overlap stars the scatter is a little larger, roughly 3.5 percent, overall. The larger scatter for the overlap stars after the split date may be due to the development of the fatigue spot; the counts measured will be too high if the measurement is not taken very close to the reference point. In general practice the FES counts are recorded just before the final, accurate centering of the star before it is placed into the aperture. So the fatigue spot can be a significant source of error for some FES measurments.

We note that the scatter of points around the fit is not quite Gaussian. This is noticeable for the underlap stars, where a few points always seem to fall higher than the rest. However this is not a strong effect, and no attempt was made in the analysis to take this into account.

IV. Results

Our analysis indicates that a good correction for the decreasing sensitivity of the FES can be made using a linear correction after a specific date. The parameters of the final fits are given in Table 2. The new time correction can be applied in the following way:

For overlap stars, if T > 1981.65 then

$$FES(corr) = FES(obs) / (1 - .0413 (T - 1981.65))$$

For underlap stars, if T > 1980.60 then

$$FES(corr) = FES(obs) / (1 - .0291 (T - 1980.60))$$

These values indicate that by 1989, the FES has lost 30 percent of its sensitivity in overlap mode and 24 percent of its sensitivity in underlap mode. The scatter in the relationships is roughly 3 percent.

V. Future Work

There is some indication in Figures 4 and 5 that the rate of the FES sensitivity decrease is starting to lessen. This "turn-up" is more visible when very recent data are added to the plots (Barylak 1989). Thus a reanalysis will very likely be needed when enough data are obtained to determine the nature of the change.

It is expected that, sometime late this summer, a new FES reference point will be implemented. This decision was made by the IUE Three Agencies due to the difficulties caused by the "fatigue spot" at the current reference point. At that time, FES data on the calibration stars at the current reference point will no longer be collected.

Therefore, for these two reasons, we expect to redo this analysis later this year using the "final" set of data for the calibration stars. This should provide a final time correction for FES data that can be agreed upon by the IUE Three Agencies. At that time, work can begin to rederive the other calibration terms, including the dead-time correction, the zero-point scale, and the color correction.

Table 2
Parameters of the Final Linear Fits

Underlap stars

Split date: 1980.60

First fitted line:

Slope = 0 (assumed)
Intercept = 1 (assumed)

Scatter around line = 0.02405

Second fitted line:

Slope = -7.96037E-5 per day	(+/- 1.42487E-6 sigma)
Slope = -0.02908 per year	(+/- 0.00052)
Intercept = 1.0795 (at 1978.0)	(+/- 0.00405 sigma)

Scatter around line = 0.03160

Correlation coef = -0.88443

Overlap stars

Split date: 1981.65

First fitted line:

Slope = 0 (assumed)
Intercept = 1 (assumed)

Scatter around line = 0.03023

Second fitted line:

Slope = -1.13171E-4 per day	(+/- 2.85406E-6 sigma)
Slope = -0.04134 per year	(+/- 0.00104)
Intercept = 1.1503 (at 1978.0)	(+/- 0.00285 sigma)

Scatter around line = 0.03758

Correlation coef = -0.90854

References:

Barylak, M. 1989, Report to the Three Agencies.

Barylak, M., Wasatonic, R., and Imhoff, C. 1985, NASA IUE Newsletter No. 26, pg. 101.

Holm, A., and Crabb, W. 1979, NASA IUE Newsletter No. 7, pg. 40.

Holm, A., and Rice, G. 1981, NASA IUE Newsletter No. 15, pg. 74.

Imhoff, C. L., and Wasatonic, R. 1986, NASA IUE Newsletter No. 20, pg. 45.

Sonneborn, G., Oliversen, N. A., Imhoff, C. L., Pitts, R. E., and Holm, A. V. 1987, NASA IUE Newsletter No. 32, pg. 1.

Stickland, D. 1980, ESA IUE Newsletter No. 5, pg 30.

Figure Captions

Figure 1. Normalized FES counts for calibration stars obtained with the FES overlap mode (dots) and underlap mode (x) versus time (4000 days after 1978 is about 1989.0). Note that the sensitivity decrease is greater for the overlap mode, probably due to the development of the fatigue spot at the reference point.

Figure 2a. Mean scatter for the two lines fitted to the overlap star data, as functions of the split date. One can see that the scatter is smallest for lines fitted to the data before the split date (x) if the split date is chosen to be in mid-1980. For lines fitted to data after the split date (+), the scatter is smallest around early 1981.

Figure 2b. FES counts at the split date for the two lines fitted to the overlap star data, as functions of the split date. One can see that the FES counts at the split date for the line fitted to data after the split date (+) are 1.0 in mid-1981. The FES counts at the split date for the line fitted to date before the split date (x) stay close to 1 until 1982 and later. Using this information as the prime criterion, a split date of 1981.65 was adopted.

Figure 3a. Mean scatter for the two lines fitted to the underlap star data, as functions of the split date. One can see that the scatter is smallest for lines fitted to the data before the split date (x) if the split date is chosen to be in early 1980. For lines fitted to data after the split date (+), the scatter is roughly constant.

Figure 3b. FES counts at the split date for the two lines fitted to the underlap star data, as functions of the split date. One can see that the FES counts at the split date for the line fitted to data after the split date (+) are 1.0 in mid-1980. The FES counts at the split date for the line fitted to date before the split date (x) stay close to 1 until 1983 and later. Using this information as the prime criterion, a split date of 1980.60 was adopted.

Figure 4. FES data for the calibration stars obtained using FES overlap mode, overplotted with the final fitted lines.

Figure 5. FES data for the calibration stars obtained using FES underlap mode, overplotted with the final fitted lines.

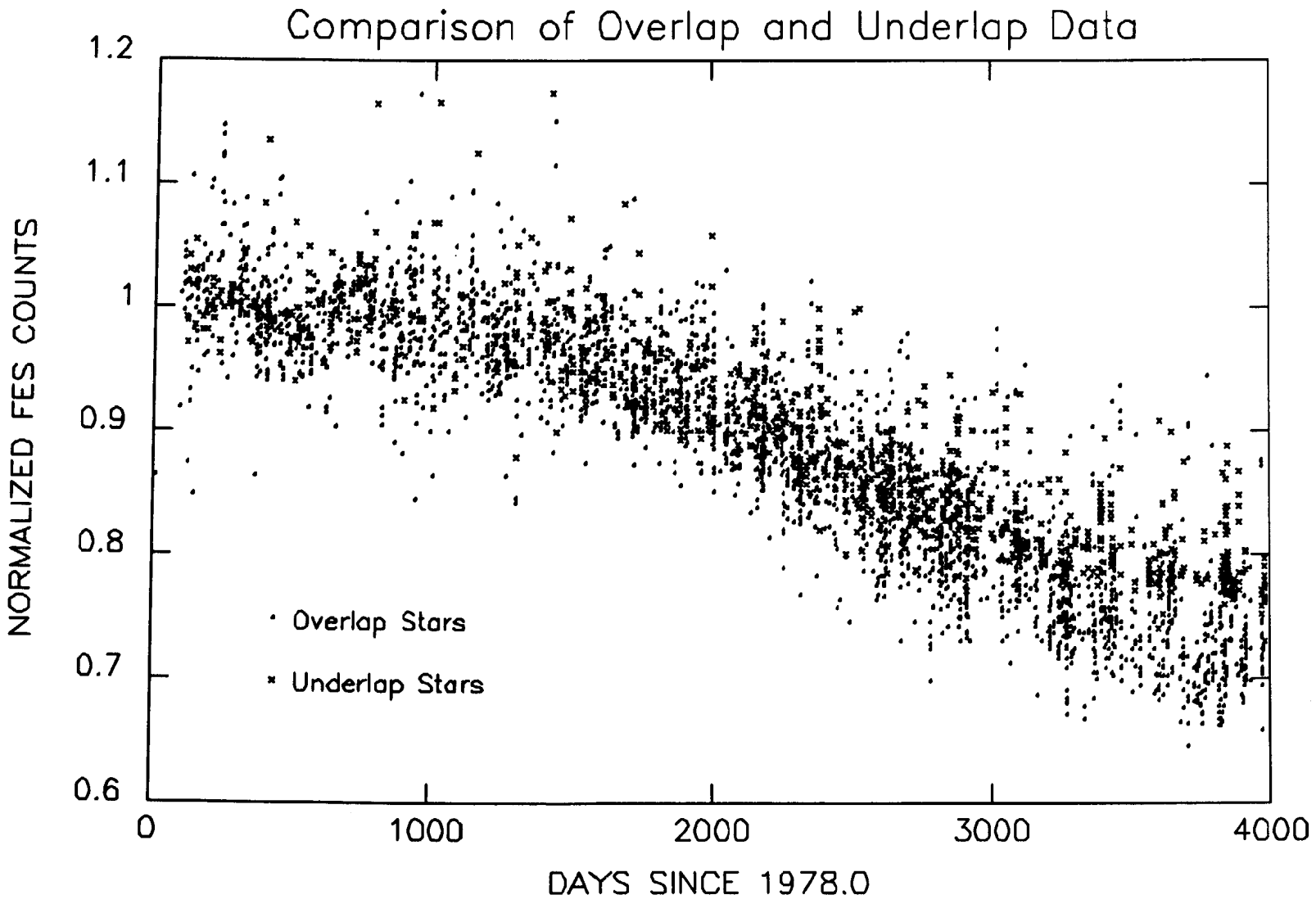
Comparison of Overlap and Underlap Data
NORMALIZED FES COUNTS
1.2
1.1
1
0.9
0.8
0.7
0.6
0
1000
2000
3000
4000
DAYS SINCE 1978.0
Overlap Stars
Underlap Stars

Fig. 1

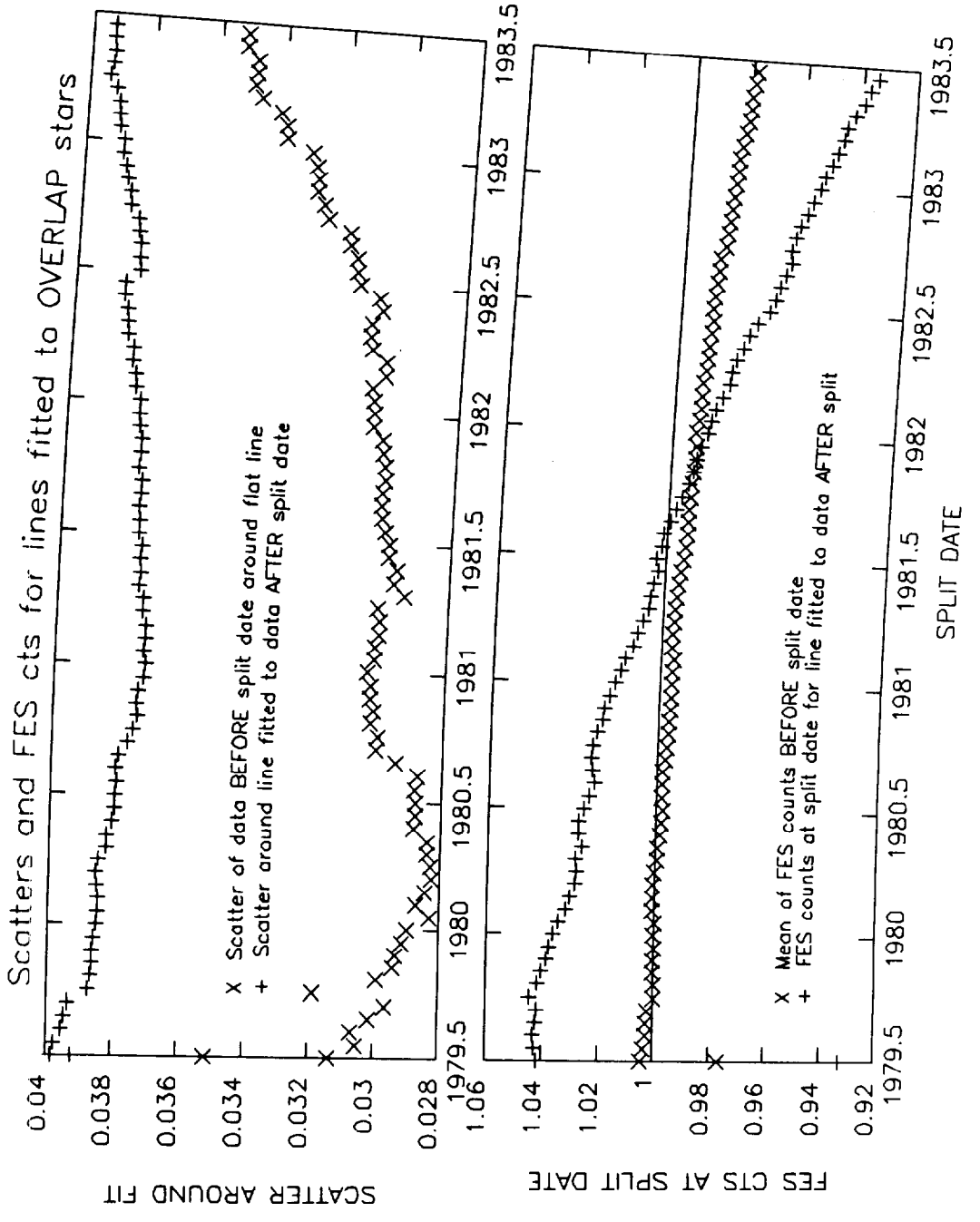
Scatters and FES cts for lines fitted to OVERLAP stars
X Scatter of data BEFORE split date around flat line
+ Scatter around line fitted to data AFTER split date
SCATTER AROUND FIT
0.04
0.038
0.036
0.034
0.032
0.03
0.028
X Mean of FES counts BEFORE split date
+ FES counts at split date for line fitted to data AFTER split
FES CTS AT SPLIT DATE
1.06
1.04
1.02
1
0.98
0.96
0.94
0.92
1979.5
1980
1980.5
1981
1981.5
1982
1982.5
1983
1983.5
SPLIT DATE

Fig. 2

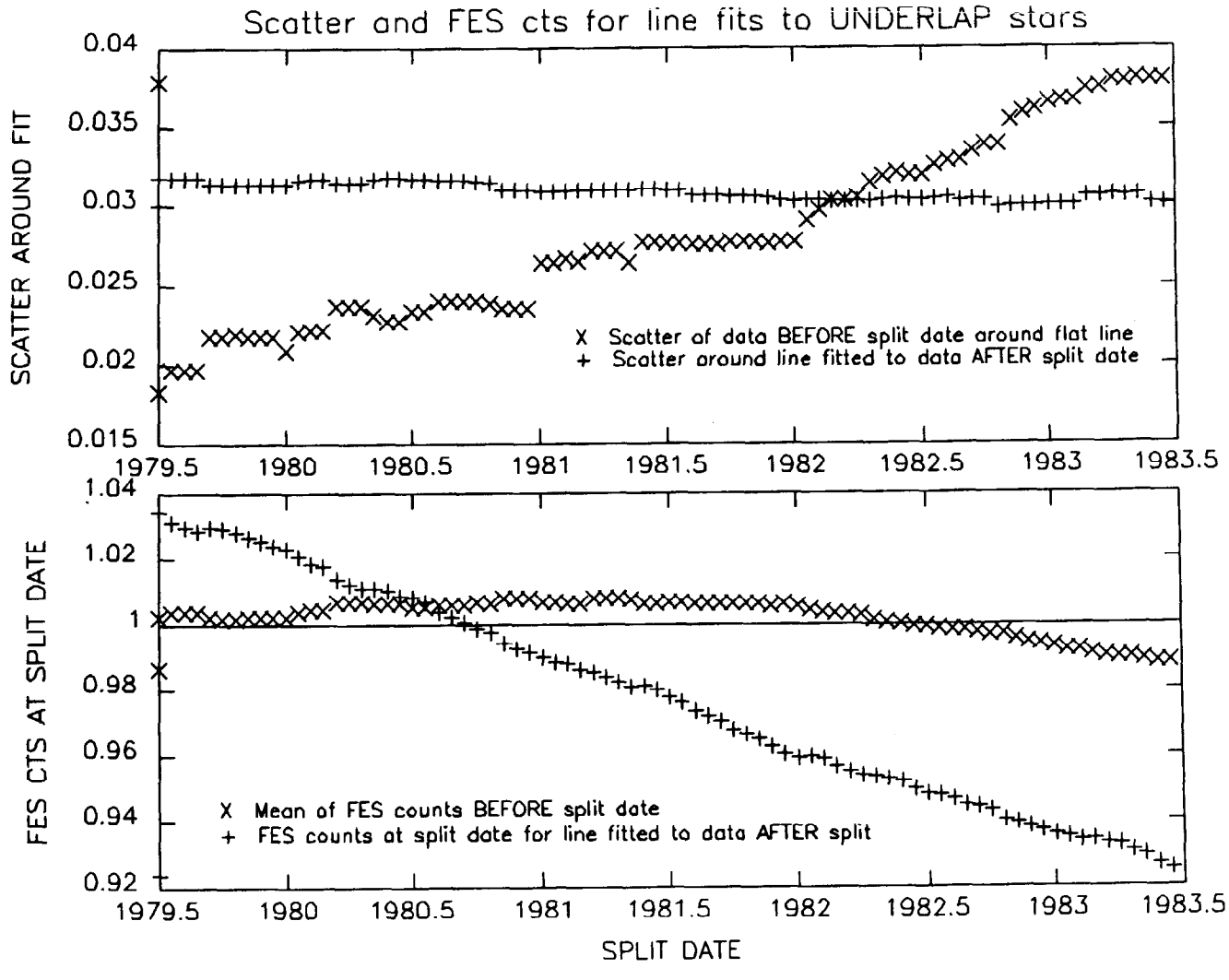
Scatter and FES cts for line fits to UNDERLAP stars
SCATTER AROUND FIT
0.04
0.035
0.03
0.025
0.02
0.015
X Scatter of data BEFORE split date around flat line
+ Scatter around line fitted to data AFTER split date
1979.5
1980
1980.5
1981
1981.5
1982
1982.5
1983
1983.5
FES CTS AT SPLIT DATE
1.04
1.02
1
0.98
0.96
0.94
0.92
X Mean of FES counts BEFORE split date
+ FES counts at split date for line fitted to data AFTER split
SPLIT DATE

Fig. 3

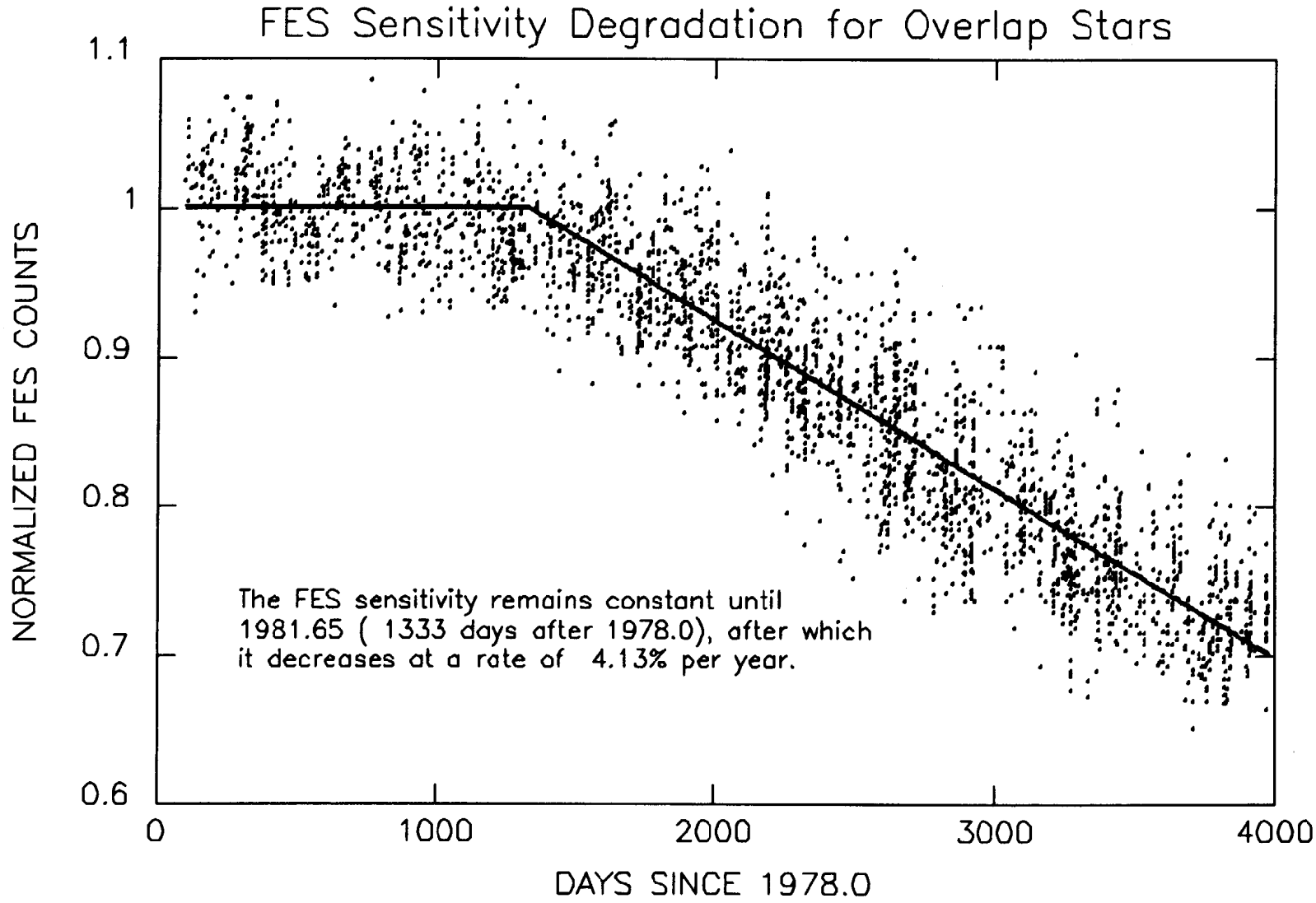
FES Sensitivity Degradation for Overlap Stars
NORMALIZED FES COUNTS
1.1
1
0.9
0.8
0.7
0.6
0
1000
2000
3000
4000
DAYS SINCE 1978.0
The FES sensitivity remains constant until
1981.65 (1333 days after 1978.0), after which
it decreases at a rate of 4.13% per year.

Fig. 4

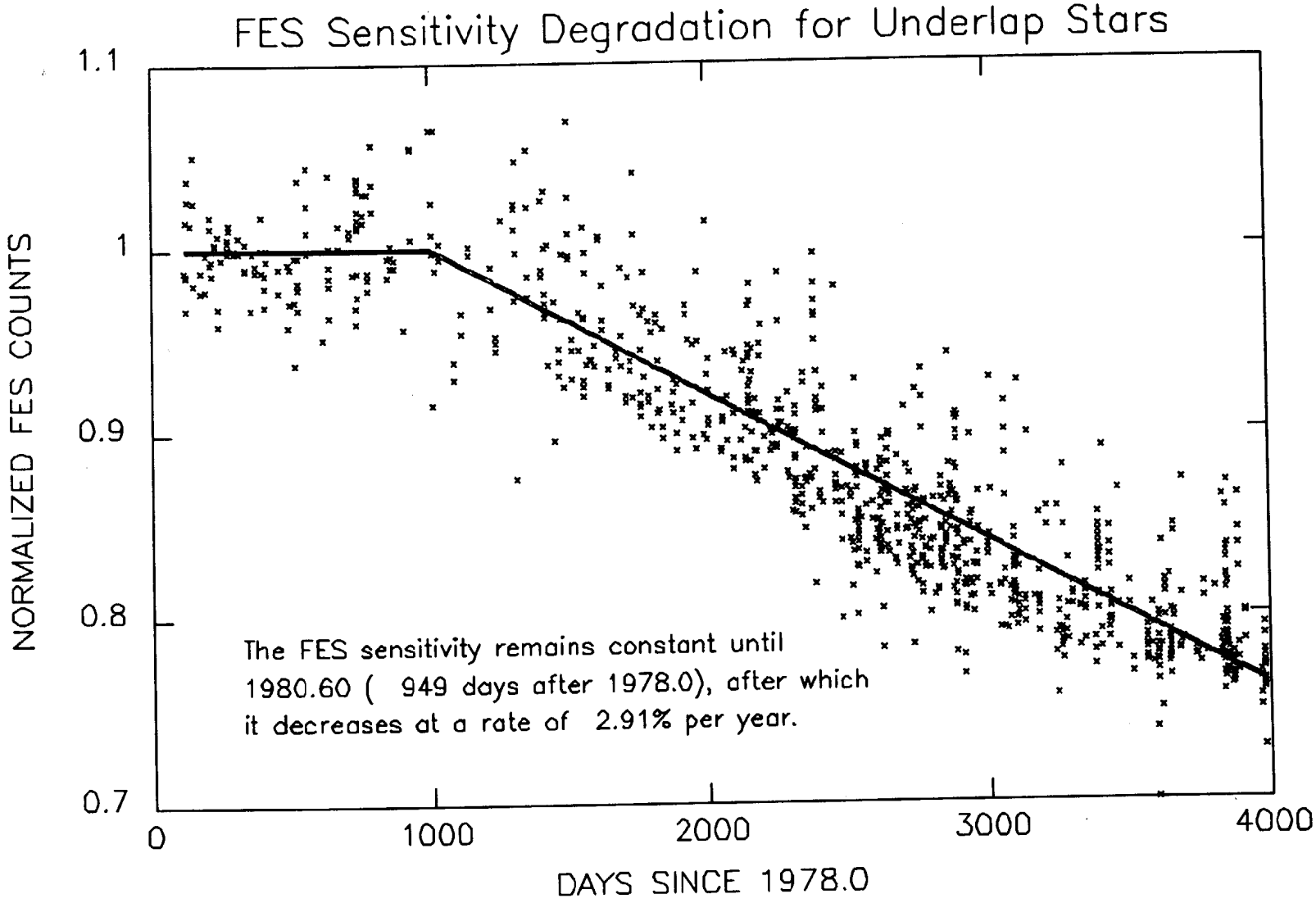
FES Sensitivity Degradation for Underlap Stars
NORMALIZED FES COUNTS
1.1
1
0.9
0.8
0.7
0
1000
2000
3000
4000
DAYS SINCE 1978.0
The FES sensitivity remains constant until
1980.60 (949 days after 1978.0), after which
it decreases at a rate of 2.91% per year.

Fig. 5