Fast Trail Technique - Progress Report
Nancy A. Oliversen
July 23, 1986

Introduction

Trails with rates of about 25 arcseconds/second or greater have historically been very unreliable. It was not uncommon for the star to graze or miss the large aperture altogether. This was unfortunate, because these trail rates are needed to obtain several of the bright calibration stars, such as Eta UMa or Alpha Lyr. About a year ago we began to experiment with a new trailing technique in an effort to improve the reliability of these fast trails. This report, which was presented at the June 1986 Three-Agency Committee Meeting, summarizes the progress made so far with the development of this new fast trail technique and presents the results on the flux levels attained with several trailed spectra of Eta UMa.

Operational Techniques

The effort at improving the fast trails was first begun while using the 3-gyro system. IUE Control Center staff produced plots of the FES X and Y values obtained from gyro telemetry during several trails performed with the "old" trailing technique. It was found that the star path oscillated wildly at the start of the slew, but eventually settled out to a straight line and uniform trail rate (see Figure 1). For all the "old" fast trails, the star would pass the aperture before the slew had settled out to a straight path. For the unsuccessful trails, the star would obviously miss the aperture, but even for the apparently successful trails, the trail rate had not yet achieved its final value. Consequently, the derived absolute flux levels were unreliable.

We decided to try backing up the star further from the aperture before starting the trail slew so that the star would pass through the aperture after the slew had settled out. This technique greatly improved the reliability of the fast trails. Trails with rates of up to about 90 arcseconds/second were successfully performed using the 3-gyro system and trails with rates of up to 120 arcseconds/second have been performed with the 2-gyro system. In fact, the majority of the Eta UMa trails for the new absolute calibrations were obtained using the two-gyro system.

Unfortunately, with the two-gyro system the true pitch and yaw motion (or FES X and Y) is not readily derivable from gyro data alone and we have been unable to produce plots similar to those of Figure 1. Consequently, the correct distance to back the star up before starting the trail slew must be determined by trial and error. When examining the image at the EDS console, several criteria can be used to determine if a particular trail has been successful or not. A successful trail is one which appears to fill the large aperture and has crossed the center of the large aperture. The SWP large and small apertures are aligned along the expected trail path, while the long wavelength small aperture lies off the trail path. The presence of a small aperture spectrum next to the trailed spectrum is therefore, an indication of a poor LWP or LWR trail and a good SWP trail. This is basically a measure of the error along the short axis of the aperture. Finally, the FES errors at the reference point after the trail has been completed should be relatively small (ideally less than 1-3 arcseconds). This is particularly important for the errors (EY) along the short axis of the large aperture.

Twenty-eight "successful" fast trails have been obtained with the 2-gyro system. The distance that the star was backed up before starting each slew versus the trail rate is plotted in Figure 2. The trail rate and backup distance for three sample trails at rates of 15, 20 and 25 arcseconds/second have also been included in the plot. The backup distance for each of these 3 trails was derived using the standard trail procedure. A second-order polynomial was fit to the resulting 31 points. It can been seen from Figure 2 that this second-order polynomial predicts the backup distance quite well. The needed backup distance (arcminutes) can be predicted by:

$$\text{Backup distance} = 0.616 - 0.157*TR + 0.005*TR^2$$

where TR is the trail rate (arcseconds/second).

Repeatability

The 13 trailed spectra of Eta UMa, which were acquired for the new absolute calibration, have been analyzed to study the repeatability of the fast trails. Table 1 summarizes the images which have been included in this analysis (4 SWP, 4 LWP and 5 LWR). For each image the trail rate, backup distance, peak DN level, and FES errors after the completion of the trail are listed. Each trail rate was chosen to give an optimum exposure level of about 200 DN near the sensitivity peak of the camera. Two of the early SWP spectra (SWP 26247, SWP 26249) were obtained while the fast trail technique was still being optimized. Consequently, the backup distance chosen for these two images was not as large as would have been ideal and one image (SWP 26249) grazed the aperture. One of the LWR spectra, despite using a backup distance comparable with the other LWR spectra also grazed the aperture (LWR 17822). Finally, the flux level for one of the LWR images (LWR 17747) turned out to be too low by about 10% when compared to the remaining 3 LWR trails. The measured FES EY error after this trail was completed was +13, which apparently was an indication that the star grazed the large aperture. These three images have not been included in the following analysis.

The May 1980 absolute calibration was used to derive the SWP and LWR fluxes, while the December 1983 calibration was used to derive the LWP fluxes (Bohlin and Holm, 1980; Cassatella and Harris, 1983). The exposure time for each spectrum was assumed to be equal to the trail path divided by the trail rate. The trail path (SWLA=21.4±.4 arcseconds, LWLA=20.5±1.0 arcseconds) is given by Panek (1982). Each spectrum was corrected to an average camera temperature (THDA). The LWR spectra have been corrected for sensitivity degradation using the method of Clavel et al. (1985), while the LWP and SWP spectra have not been corrected for sensitivity degradation. Note that the LWR sensitivity degradation rates reported by Clavel et al. (1985) are in error by a small amount (Clavel et al., 1986). The erroneous rates tend to over-correct the flux levels. The corrected degradation rates have been used for this report. Average spectra were then derived by coadding the 4 LWP spectra, the 3 best LWR spectra and the 3 best SWP spectra. Finally, each spectrum was ratioed to the corresponding average spectrum. The derived flux levels of these 10 fast trailed spectra were repeatable to an accuracy of between 2 to 5%, which is comparable to the repeatability of point-source and trailed spectra obtained at lower speeds.

Absolute Flux Levels

The average spectra were binned into 25 Angstrom bins. These binned data were then compared to the Eta UMa fluxes published by Bohlin and Holm (1984). The averaged spectra and the Bohlin and Holm fluxes are shown in Figures 3a, 5a and 7a for the SWP, LWR and LWP cameras, respectively. Finally, the ratios of the binned average spectra to the Bohlin and Holm fluxes are shown in Figures 3b, 5b and 7b.

The SWP fast trail flux level appears to be the closest to the Bohlin and Holm fluxes for the three cameras. The binned SWP fluxes are too low by an average of about 6%. The majority of this flux error is probably due to the sensitivity decline of the SWP camera, which is about 0.5% per year. The derived flux value is well within the quoted 10% flux error level for IUE spectra in general.

The LWR fast trail flux level also is fairly close to the Bohlin and Holm fluxes over most of the spectrum. However, the derived flux level is too high by about 8% near the 2200 A to 2400 A region and too high by about 20% on the long wavelength end of the LWR. In the wavelength region between 2400 A to 3100 A, the derived flux value is accurate to about ±3%. However, these results are influenced by uncertainties in correcting for sensitivity degradation.

Initially, one might expect that the fast trail fluxes, if anything, would be less than the Bohlin and Holm fluxes due to light loss as the star grazed the aperture. However, the LWP fast trail fluxes are consistently too high compared to the Bohlin and Holm fluxes by about 11%. This is indeed peculiar! Several possibilities might account for the flux enhancement. One possiblility is that the trail path assumed for the LWP is inaccurate. The same path length was used for the reduction of the LWR and LWP trails. However, it seems unlikely that the trail path length would be different for the LWP and LWR cameras since the same aperture is used. A second possiblity might be that the trail rate of the spacecraft as the star passed the aperture was slightly different than the requested trail rate. A trail can appear to be successful on the image at the EDS console (i.e. fill the aperture), but still have an incorrect trail rate. If the trail rate is incorrect then the derived flux level will also be incorrect. Perhaps the star needs to be backed up a greater distance from the aperture before starting the slew, in order to give the trail rate more time to stabilize. However, it should be noted that both the SWP and LWR trails gave reasonable flux levels. Although the LWR trail rate is slightly faster than either the SWP or LWR, it seems unlikely that this small increase should make such a difference in the flux levels. A final possibility is that the LWP flux calibration is in error by this amount. Such a result has been suggested by several investigators (Bohlin, Wesemael, Urry, private communication).

An error in the aperture size or trail rate does not account for the LWR wavelength-dependent variation of the flux ratios. The May 1980 calibration was based on an average of large aperture, small aperture and trailed spectra. The relative response of the three types of spectra are known to be significantly different. This variation of responses potentially could introduce some of the wavelength-dependent variation of the flux level seen for the LWR. Recently, Bohlin (1986) published a revision to the absolute calibration which corrects for the relative aperture responses. This correction factor was applied to the binned LWR and SWP fast trail fluxes and compared to the Bohlin and Holm (1984) fluxes for Eta UMa (see Figure 4a,b and 6a,b). The Bohlin (1986) calibration reduces the LWR wavelength-dependant flux errors. In particular, the derived flux levels longward of about 3150 A are improved and the overall flux level is flatter.

The derived flux levels for the SWP using the Bohlin (1986) calibration were too low by an average of about 9%. In addition, a slight slope is introduced to the flux ratio. The derived flux at the long wavelength end of the SWP is depressed relative to the flux in the short wavelength region. This is also consistent with the SWP sensitivity decline which has been greatest at the long wavelength end of the camera (Sonneborn, 1984).

What Next?

The above polynomial expression for the backup distance as a function of the trail rate will be used to modify the TRAIL procedure in the next procedure file. This should greatly improve the accuracy of the fast trails and make their acquisition easier. Note that the potential will still exist for grazing the aperture, but it is unlikely that the star will miss the aperture altogether.

Additional spacecraft tests are planned and further modifications may be made to the fast trail procedure pending the results of these tests. In particular, additional tests are needed for the highest trail rates (> 90 arcseconds/second) to determine the optimum backup distance. Relatively few trails have been obtained with these high rates. In addition, tests are planned to vary the backup rate before starting the trail slew. In the worst case, it can take more than 5 minutes to back the star up before starting the trail slew. Gyro thermal drift can cause the star to graze the aperture if the gyros are not trimmed very well before starting these trails. Tests will be made to determine the fastest backup rate possible without degrading the trail accuracy.

References

Bohlin, R. and Holm, A. 1980, NASA IUE Newsletter, 10, 37.

Bohlin, R. and Holm, A. 1984, NASA IUE Newsletter, 24, 74.

Bohlin, R. 1986, Ap. J., in press; NASA IUE Newsletter, 29, 66.

Cassatella, A. and Harris, A. 1983, NASA IUE Newsletter, 23, 21.

Clavel, J., Gilmozzi, R. and Prieto, A. 1985, NASA IUE Newsletter, 27, 50.

Clavel, J., Gilmozzi, R. and Prieto, A. June 1986, Report presented at the IUE Three-Agency Committee Meeting.

Panek, R. 1982, NASA IUE Newsletter, 18, 68.

Sonneborn, G. 1984, NASA IUE Newsletter, 24, 67.

Table 1
Fast Trail Spectra of Eta UMa

Image Number	Trail Rate (arcsec/sec)	Backup Dist. (arcmin)	Max. Expo. Level (DN)	FES Errors EX/EY	SMAP Visible?	Comments
Two-gyro trails:						
LWR 17822	69	30	159	0/2	yes	Spectrum asymmetric
LWR 17823	69	30	200	-3/0	no	
LWR 17824	69	30	203	-3/0	no	
LWP 7208	88.5	50	208	-12/1	no	
LWP 7209	88.5	50	197	-14/0	no	
LWP 7218	88.5	50	208	-11/-2	no	
SWP 27196	69	35	196	-8/1	yes	
SWP 27204	69	35	205	-6/0	yes	
Three-gyro trails:						
LWR 17745	69	25	195	-10/-1	no	
LWR 17747	69	30	205	-11/13	yes(faint)	Flux level down by 10%
LWP 6383	88.5	45	195	-28/-8	no	DN level comparable to other LWP images despite high EX
SWP 26247	60	15	217	-9/5	yes	
SWP 26249	69	15	205	-3/-2	yes	Spectrum asymmetric

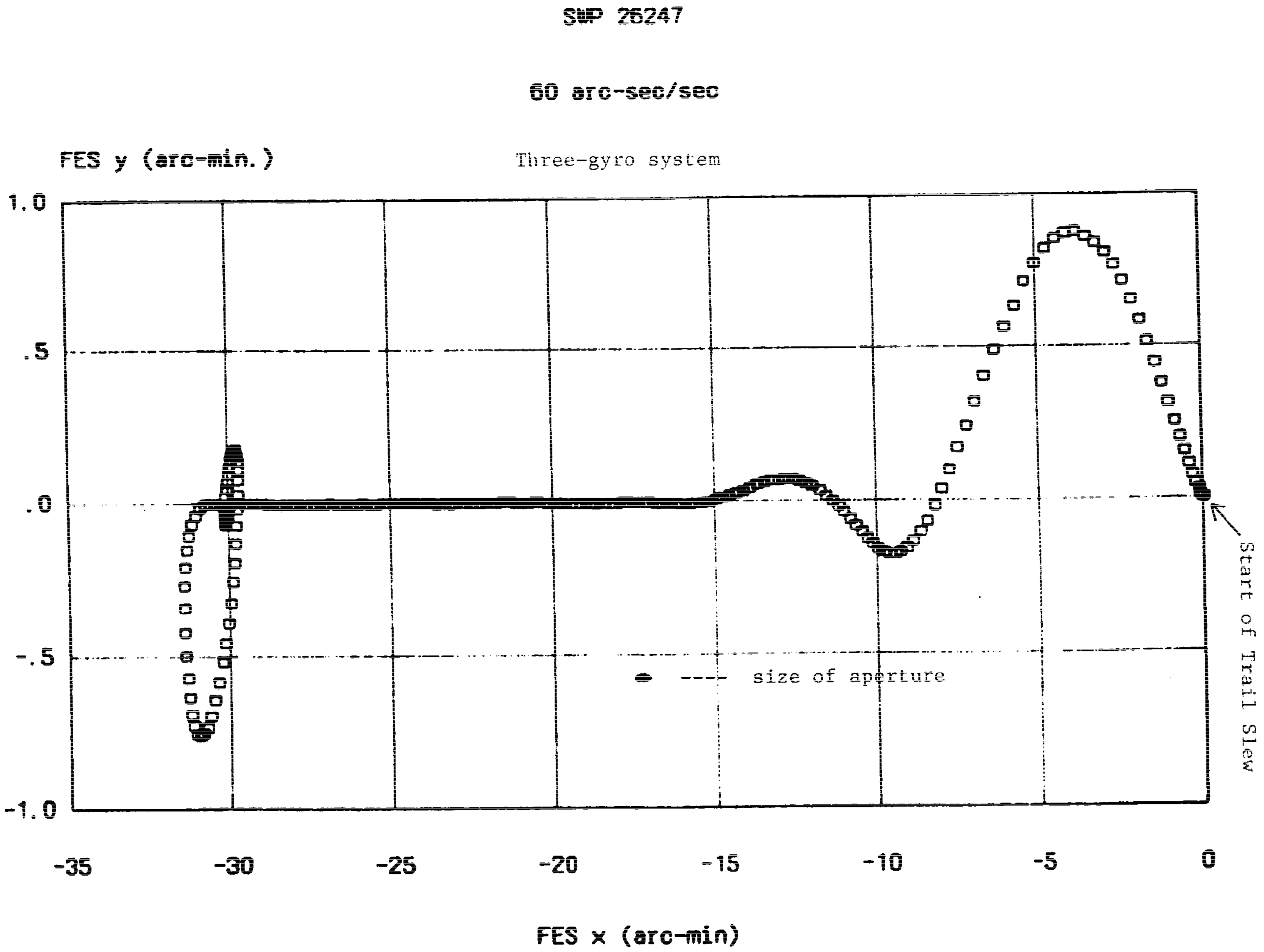


Figure 1. Trail path for 60 arcsec/sec trail

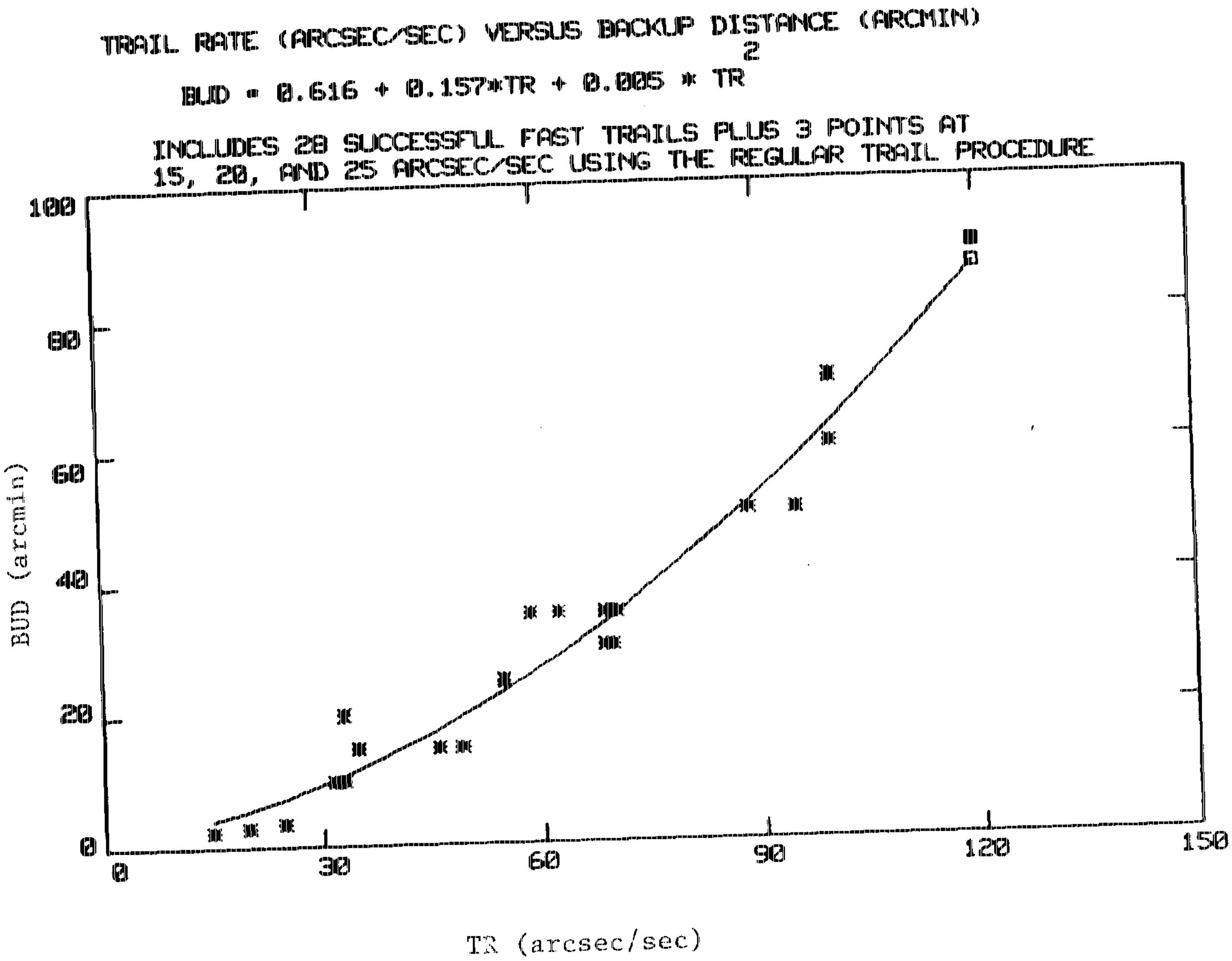

TRAIL RATE (ARCSEC/SEC) VERSUS BACKUP DISTANCE (ARCMIN)
$BUD = 0.616 + 0.157*TR + 0.005 * TR^2$
INCLUDES 28 SUCCESSFUL FAST TRAILS PLUS 3 POINTS AT
15, 20, AND 25 ARCSEC/SEC USING THE REGULAR TRAIL PROCEDURE
BUD (arcmin)
100
80
60
40
20
0
0
30
60
90
120
150
TR (arcsec/sec)

Figure 2.

Figure 3a. ETA UMA FAST TRAILED SPECTRA
SOLID LINE = AVERAGE OF SWP 27196, 27204 AND 27247
MAY 1980 CALIBRATION USED

* = FLUXES FROM BOHLIN AND HOLM, 1984

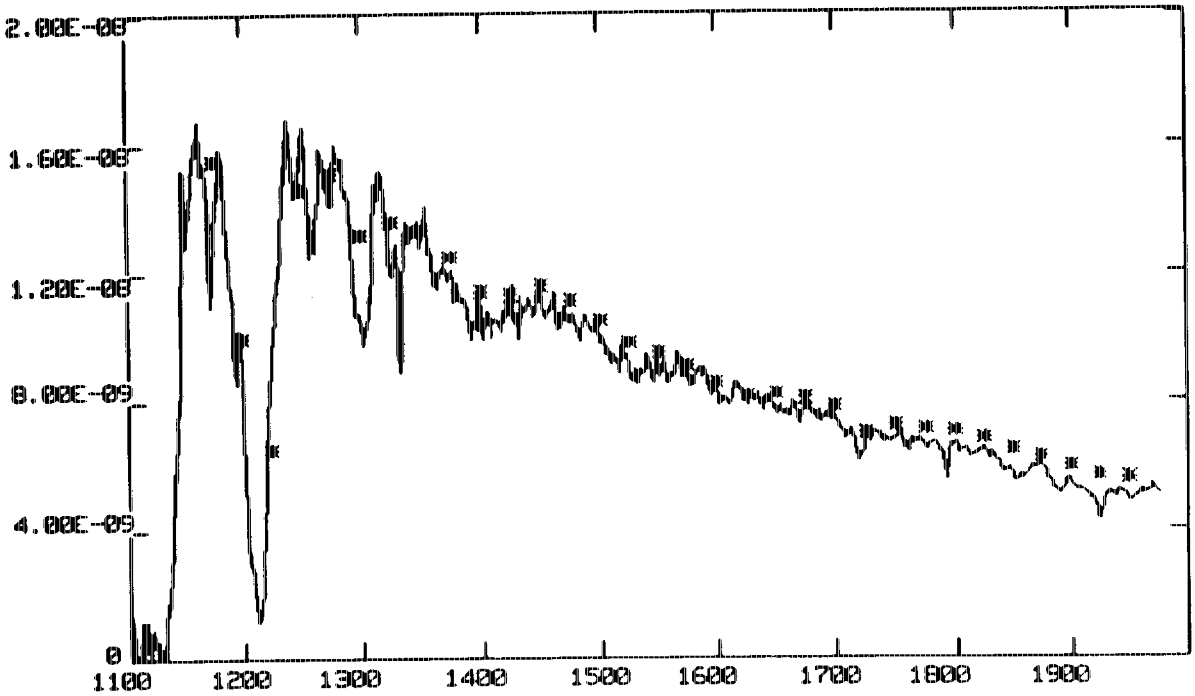


Figure 3b. SWP RATIO OF BINNED FAST TRAILED FLUXES OF ETA UMA
TO BOHLIN AND HOLM (1984) FLUXES
MAY 1980 CALIBRATION USED FOR FAST TRAILED FLUXES

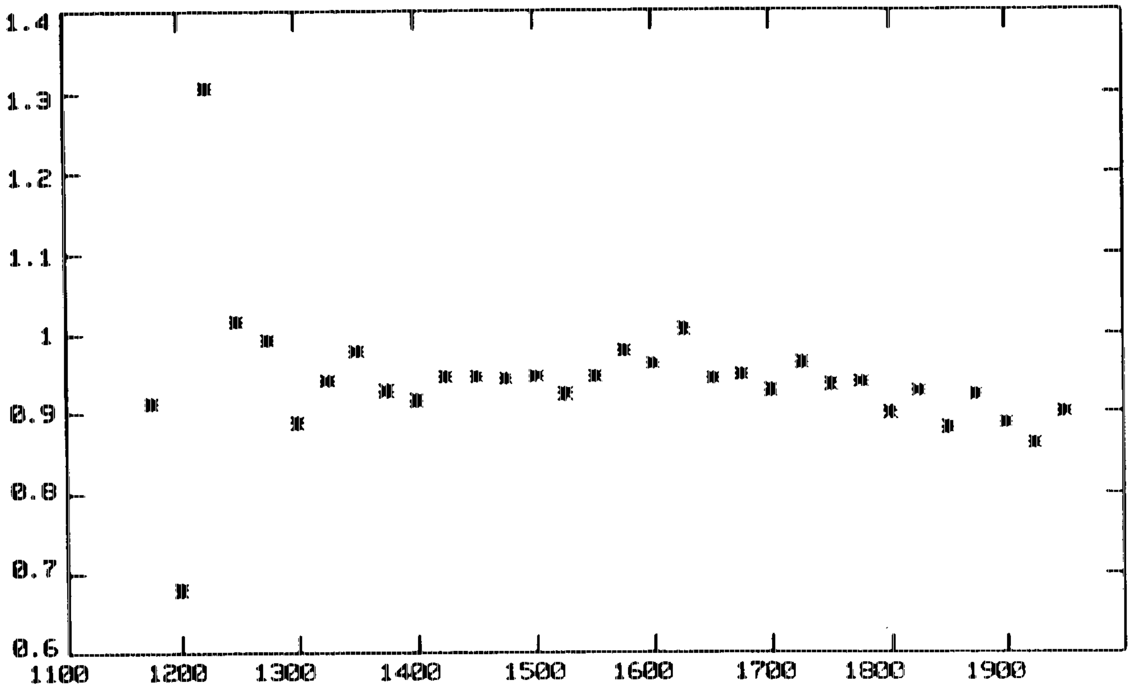


Figure 4a. ETA UMA FAST TRAILED SPECTRA
HISTOGRAM = AVERAGE OF SWP 27196, 27204, AND 27247
BOHLIN, 1986 CALIBRATION USED

* = BLUXES FROM BOHLIN AND HOLM, 1984

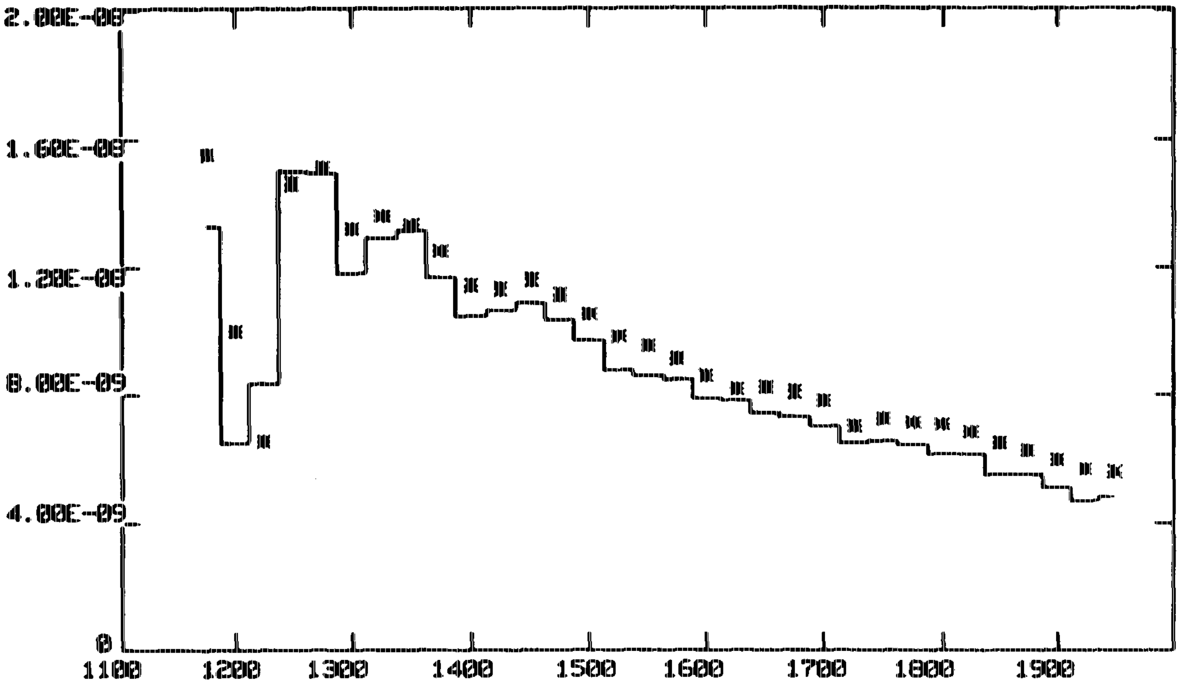


Figure 4b. SWP RATIO OF BINNED FAST TRAILED FLUXES OF ETA UMA TO
BOHLIN AND HOLM (1984) FLUXES
BOHLIN (1986) CALIBRATION USED FOR FAST TRAILED FLUXES

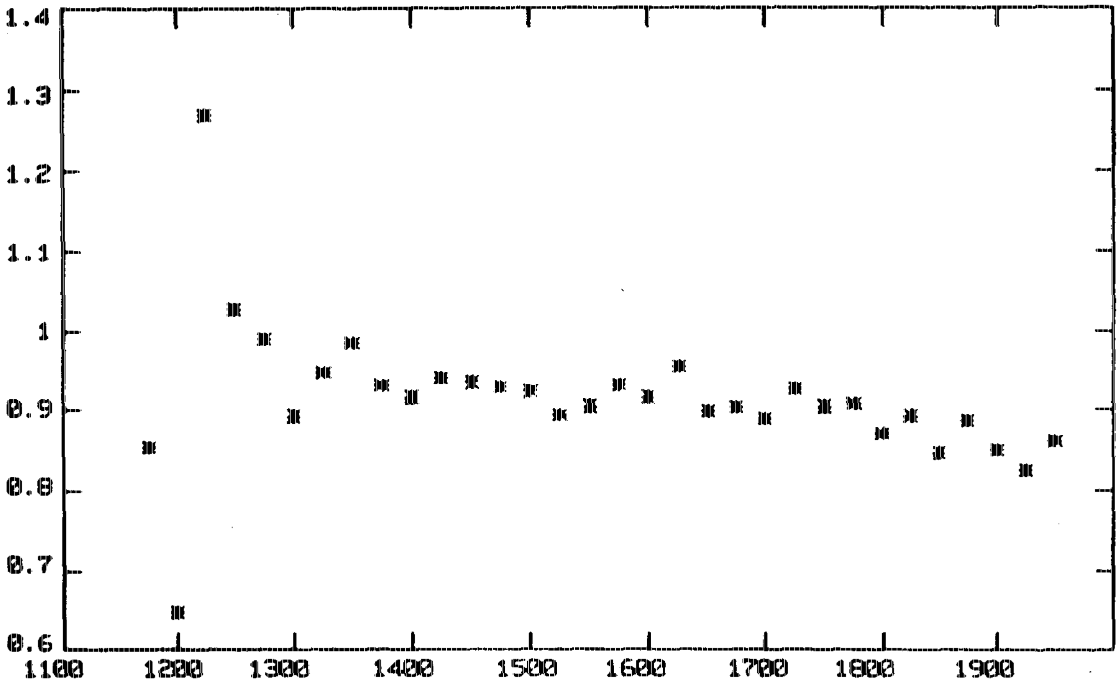


Figure 5a. ETA UMA FAST TRAILED SPECTRA
SOLID LINE = AVERAGE OF LWR 17745, 17823 AND 17824
MAY, 1980 CALIBRATION USED, LWR SENS. DEGRAD. CORR. APPLIED
* = FLUXES FROM BOHLIN AND HOLM (1984)

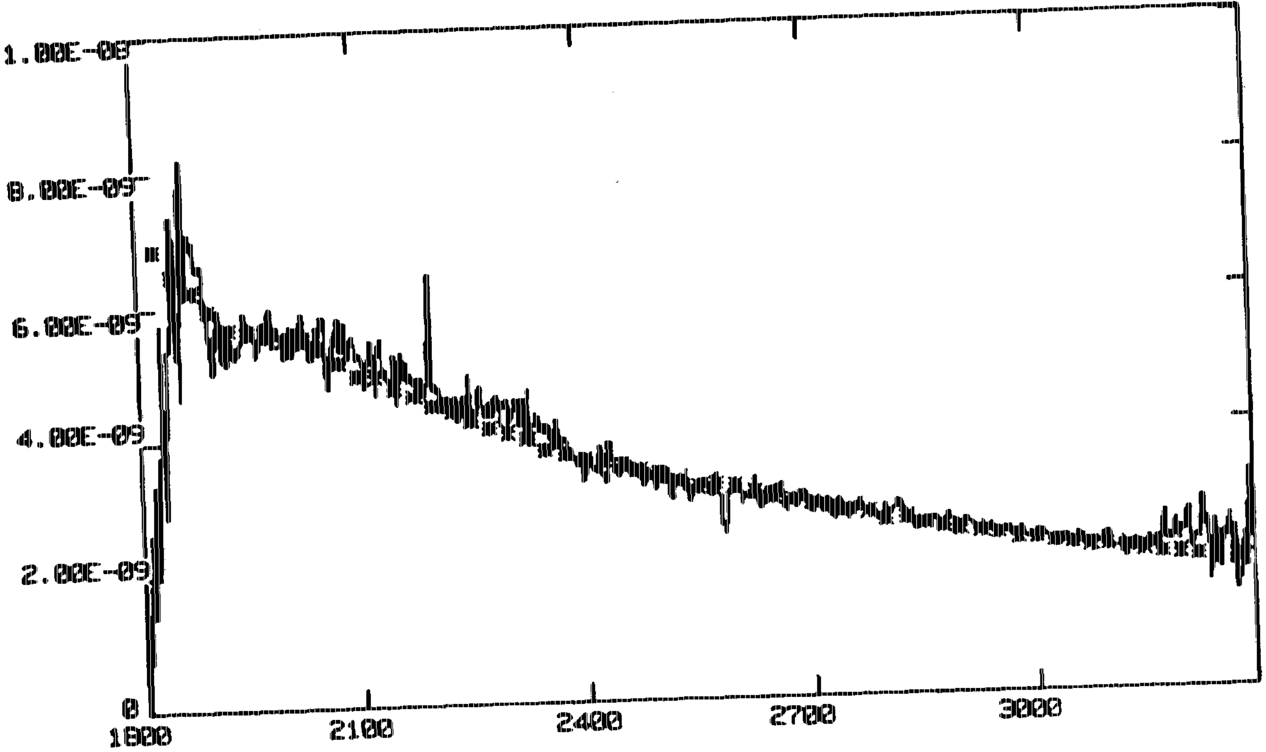


Figure 5b. LWR RATIO OF BINNED FAST TRAILED FLUXES OF ETA UMA TO
BOHLIN AND HOLM (1984) FLUXES
MAY 1980 CALIBRATION USED FOR FAST TRAILED FLUXES

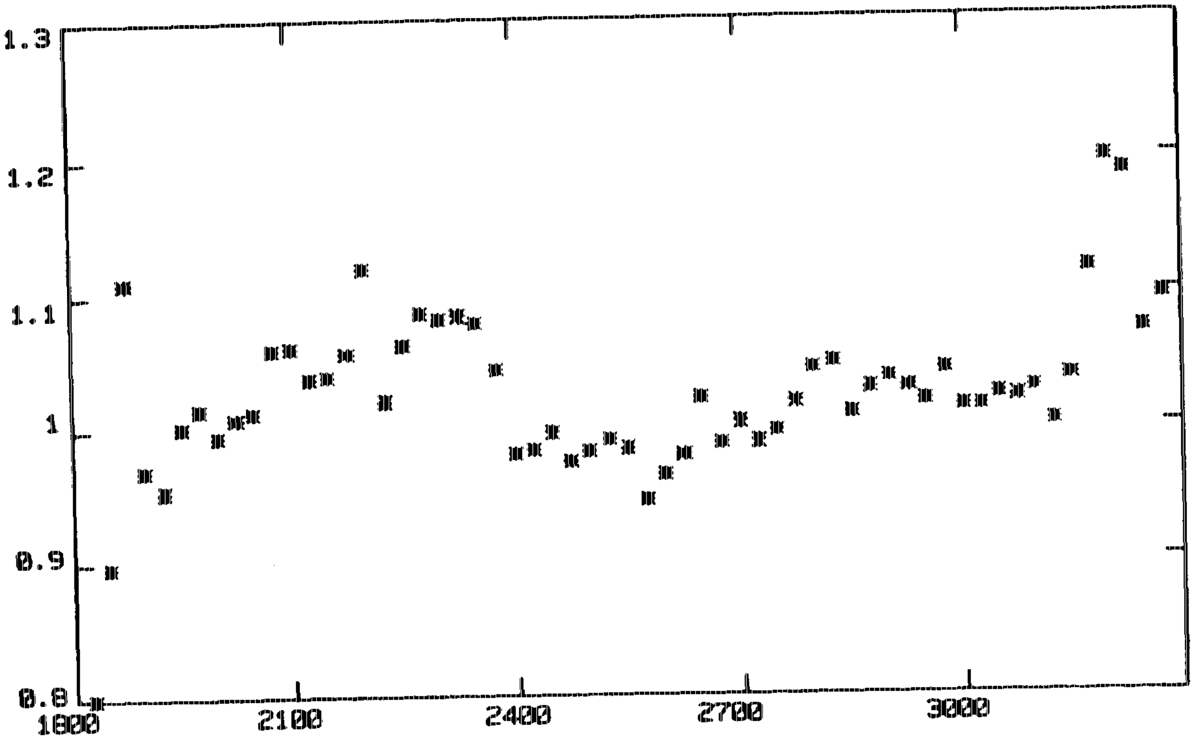


Figure 6a. ETA UMA FAST TRAILED SPECTRA
HISTOGRAM = AVERAGE OF LWR 17745, 17823, AND 17824
BOHLIN, 1986 CALIBRATION USED, LWR SENS. DEGRAD. CORR. APPLIED
* = FLUXES FROM BOHLIN AND HOLM (1984)

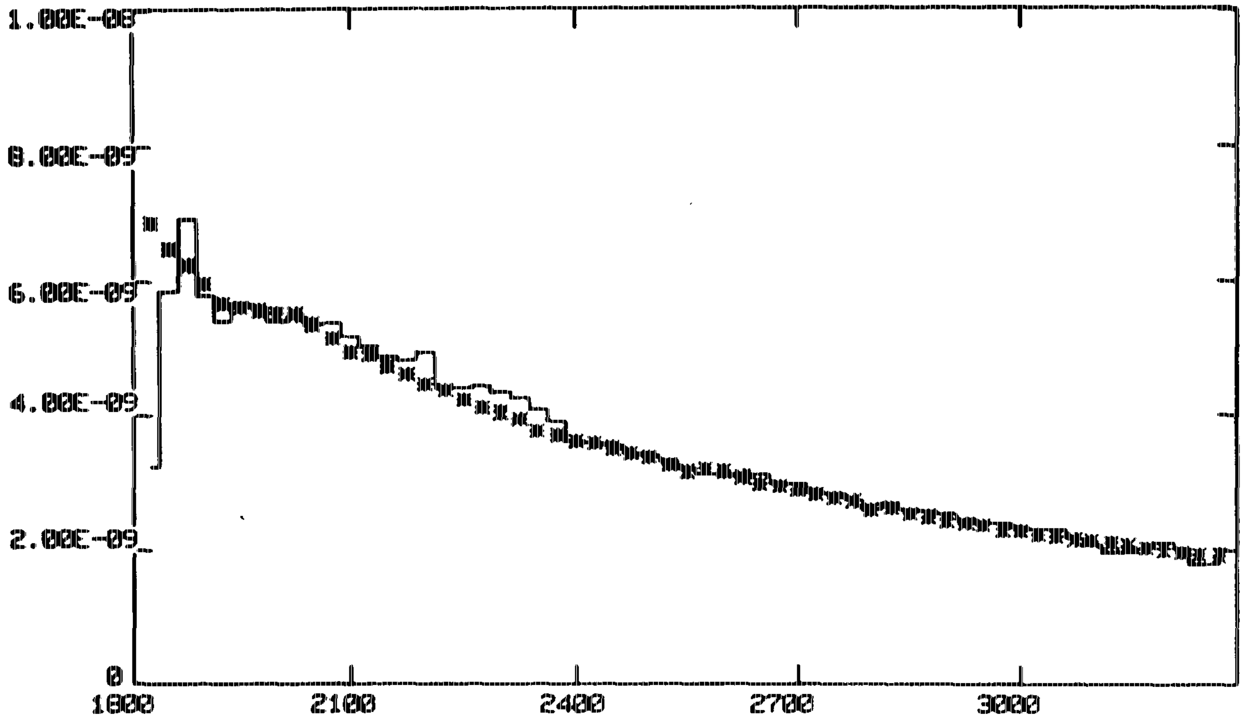
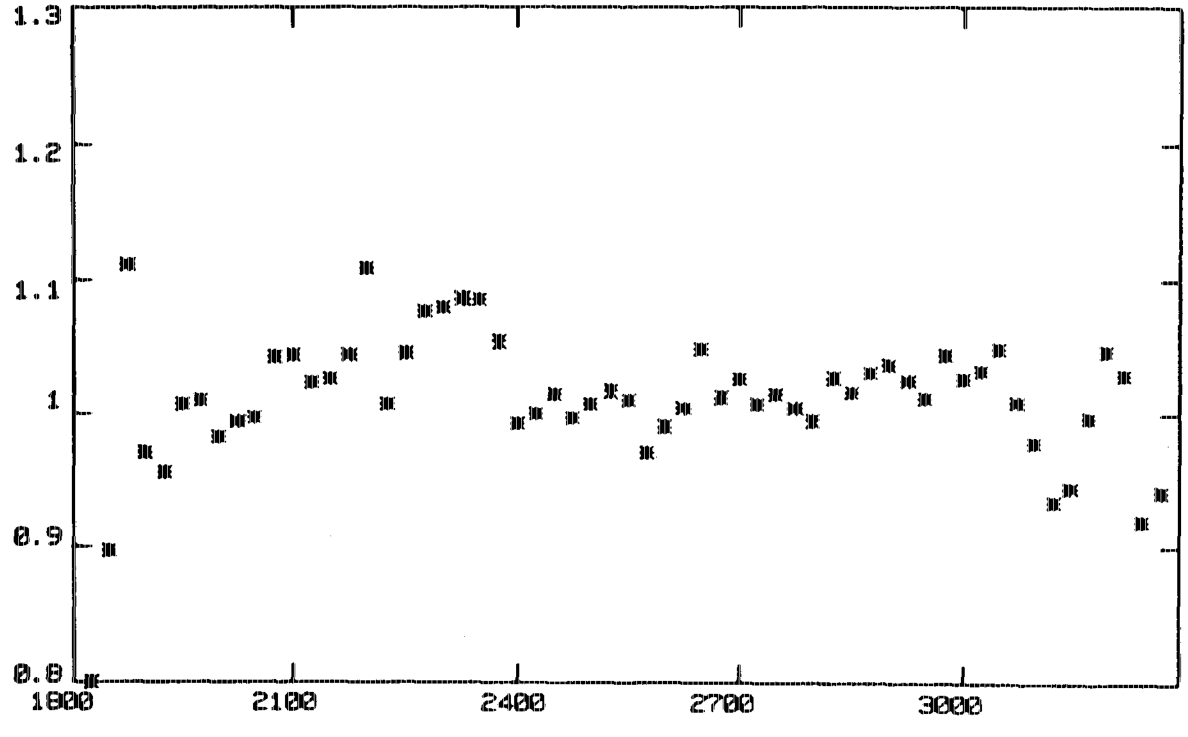
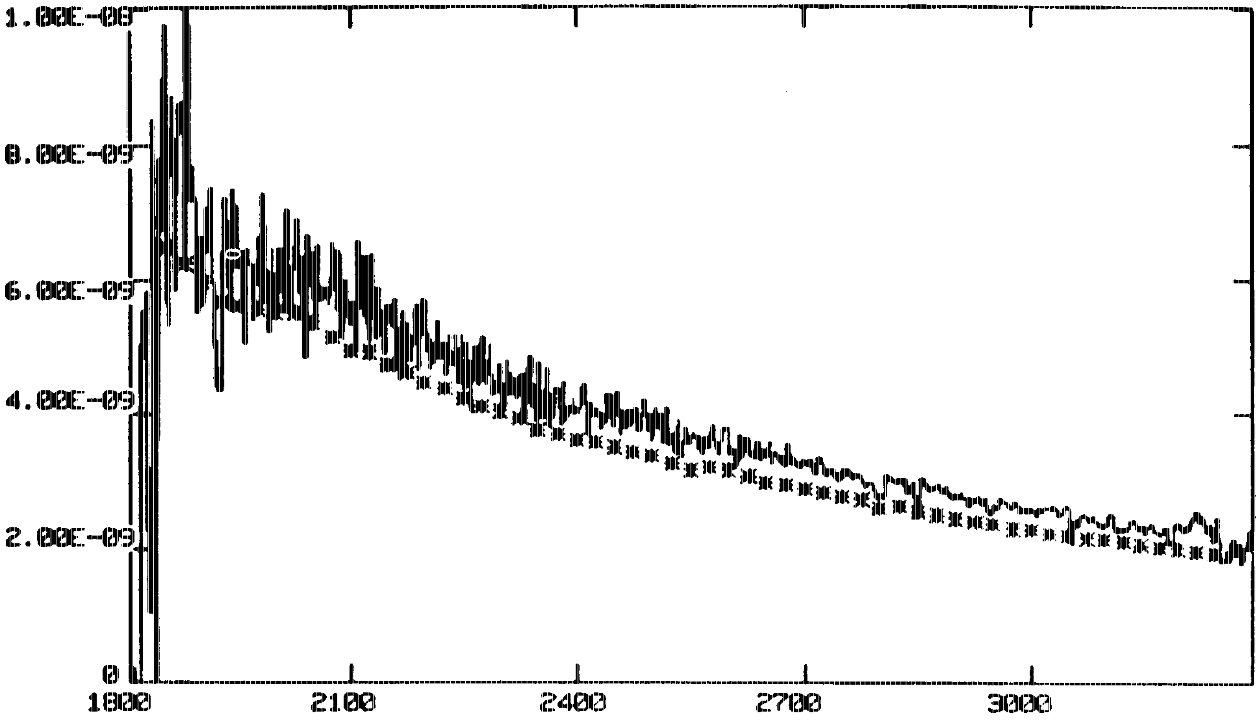


Figure 6b. LWR RATIO OF BINNED FAST TRAILED FLUXES OF ETA UMA TO
BOHLIN AND HOLM (1984) FLUXES
BOHLIN (1986) CALIBRATION USED FOR FAST TRAILED FLUXES



ETA UMA, AVERAGE OF 4 LWP TRAILS, 88.5 ARCSEC/SEC
(LWP 6383, 7208, 7209, 7218)
COMPARED TO BOHLIN & HOLM FLUXES (*)

Figure 7a.



RATIO OF LWP TRAILED SPECTRA OF ETA UMA (4 AVERAGED TOGETHER)
TO FLUXES OF BOHLIN AND HOLM

Figure 7b.