INITIAL CALIBRATION

In March, 1978, R. Bohlin and B. Savage obtained seventy images to evaluate the instrumental performance, and to find the absolute sensitivity. To date, these images have been only partially reduced and analyzed. All data were obtained with the cameras in their current configuration (SPREP).

The following standard stars were observed in addition to many images using the on-board lamps.

Name	Sp. Type	V	E(B-V)
ηUMa	B3V	1.86	.02
τSco	BOV	2.84	.06
μCol	09.5V	5.17	.02
αLyr	AOV	.03	.01
HD60753	B3IV	6.69	.11

INITIAL CALIBRATION DATA

OBJECT	DISP	APER	IMAGE	t(SEC)	GMT DAY: HR
ηUMA	H	L	SWP1164	8	75:02
Pt + FF	H	S	SWP1165	120,7	75:03
ηUMA	H	S	SWP1166	10	75:04
ηUMA	H	L	LWR1168	8	75:04
Pt + FF	H	S	LWR1169	16,22	75:13
ηUMA	H	L	SWP1172	8	75:15
ηUMA	H	L	SWP1173	3	75:16
ηUMA	H	L	SWP1174	24	75:17
ηUMA	H	L	SWP1175	1	75:19
ηUMA	H	S	SWP1176	10	75:20
Pt + FF	H	S	SWP1178	120, 7	75:21
Pt + FF	H	S	LWR1170	16, 8	76:14
ηUMA	H	L	LWR1171	8	76:15
ηUMA	H	L	LWR1172	24	76:17
ηUMA	H	S	LWR1173	40	76:18
ηUMA	H	S	LWR1174	80	76:19
ηUMA	H	S	SWP1185	30	76:21
ηUMA	H	S	SWP1186	17	76:22
Pt + FF	H	S	SWP1187	120,7	76:23
Pt + FF	H	S	LWR1180	16, 8	77:12
αLyr	H	S	LWR1181	18	77:15
Pt + FF	H	S	LWR1182	16	77:15
αLyr	H	L	SWP1188	11	77:17
HD60753	L	L & S	SWP1201	7, 11	78:23
Pt + FF	L	L & S	SWP1202	2, 11	79:00
Pt + FF	H	S	SWP1204	120, 7	79:13
τSCO	H	S	SWP1205	14	79:14
Pt + FF	H	S	SWP1206	120, 7	79:15
τSCO	H	S	LWR1188	30	79:16
μCol	H	L	SWP1207	60	79:20
μCol	H	L	LWR1189	75	79:21
Pt + FF	H	S	LWR1190	16, 8	79:22
μCol	H	S	LWR1191	360	80:01
μCol	H	S	SWP1208	120	80:01

INITIAL CALIBRATION DATA (continued)

OBJECT	DISP	APER	IMAGE	t(SEC)	DAY
μCol	H	S	LWR1192	180	80:03
μCol	H	S	SWP1209	70	80:04
τSco	H	S	LWR1193	60	80:11
τSco	H	S	LWR1194	75	80:12
Pt alone	H	S	LWR1195	5	80:14
Pt alone	H	S	LWR1196	25	80:14
μCol	L	L & S	SWP1210	0.6, 1.0	80:17
μCol	L	L & S	SWP1211	1.0, 2.0	80:20
Pt + FF	L	L & S	SWP1212	2, 7	80:21
μCol	L	L & S	LWR1197	0.7, 1.0	80:22
μCol	L	L & S	LWR1198	1.5, 4.0	80:23
Pt + FF	L	L & S	LWR1199	2, 7	81:00
Pt alone	H	S	LWR1216	120	83:06
Pt alone	H	S	LWR1217	600	83:07
Pt alone	L	L & S	SWP1233	1*	83:08
Pt alone	L	L & S	SWP1234	3*	83:09
Pt alone	L	L & S	SWP1235	9*	83:10
Pt alone	L	L & S	LWR1218	1*	83:11
Pt alone	L	L & S	LWR1219	3*	83:11
Pt alone	L	L & S	LWR1220	9*	83:12
Pt alone	H	S	SWP1236	12	83:13
Pt alone	H	S	SWP1237	60	83:13
Pt alone	H	S	SWP1238	300	83:14
HD60753	L	L & S	SWP1239	13, 20	83:17
HD60753	L	L & S	LWR1221	10, 20	83:18
Pt + FF	L	L & S	LWR1222	1, 8	83:19
HD60753	L	L & S	LWR1223	13, 60	83:20
ηUMA	H	L	SWP1257	8	86:15
ηUMA	H	L	LWR1245	8	86:14
ηUMA	H	S	SWP1280	9	91:01

*Min Camera Gain. All others at Max Gain.

R. Bohlin

PHOTOMETRIC CALIBRATION OF IUE

9/7/78

III. Timing Error on the Aperture Select Mechanism

The large aper. λ Lep exposures SWP 1495-96 and ζ Cas-LWR 1471 and 1472 give a consistent shape for the IUE sensitivity curve but are systematically shifted with respect to the HV Shuttered exposures as a group. The solution is that the aper. select mechanism stays open longer than commanded by a best solution of Δt_{AP} of 150 ms ± 30 ms.

The summary of the revised exp. times and revised esponses = IUE-FN/t are given below. Note that aper. Select times are uncertain to ± 30 ms, and it is necessary to fúrther adjust t to account for this problem. Also note the calibration for the Aper. Select exposures on μ Col give a calibration curve in general agreement with the other stars, after correction of the exposure times.

					R = FN/t (actual)			
*	Image #	Nominal t	Δt = ± 30 ms	t(actual)= t + .15 Δt	1400 (2150)Å	- Ratio	1700 (2750)Å	- Ratio
λLep	SWP1495	.1024	0	.252	164167	1	86667	1
λLep	SWP1496	.205	-.03	.325	170754	1.040	88271	1.019
ζCas	LWR1471	.1024	-.03	.222	(85550)	1	(177279)	1
ζCas	LWR1472	.205	0	.355	(82732)	.967	(173025)	.976

The above ratios agree with previous indications that the broad-band reproducibility is ~± 5% on short time scales. To verify and reduce the uncertainty in the 150 ms, a sequence of 0.2, 0.4 and 0.8s (or 0.1, 0.2, and 0.4s) should be obtained on each camera using the aper. select mechanism. The star μ Col would be of the appropriate brightness for SWP.

PHOTOMETRIC CALIBRATION OF IUE

9/14/78

IV. Absolute Sensitivity for Low Dispersion, Large Aperture for Cameras SWP(3) and LWR(2) and the Data Extraction Program EXTLOW

The inverse sensitivity S^{-1} for IUE cameras SWP and LWR are shown in Figures 1 and 2, respectively. To computer the flux F for any target observed in the large aperture use the equation:

$$F\ (\mathrm{erg\ cm^{-2}\ s^{-1}\ \AA^{-1}}) = \frac{S^{-1} \times FN}{\text{exp. time (sec)}}$$

where FN is the IUE Flux Number produced by the IUE data extraction program EXTLOW. The shape of the sensitivity curves for the small apertures are nearly the same, but the absolute levels vary with the fraction of the starlight passing through the small aperture, typically between 35 and 65% with extreme ranges of 25 to 75%. The low values are usually caused by gyro drift when no active tracking is used.

This calibration is the mean sensitivity derived from 29 SWP and 24 LWR large aperture spectra of standard stars. The scatter about the mean curve is ~ ± 10% on an absolute basis. Somewhat larger scatter is observed for the stars BD+33°2642 and BD+28°4211 due to noise in the TD-1 data for these faint stars.

Earlier memos in this series were I. Calibration of the Cameras used in the Commissioning Phase, i.e. SWR and LWP; II. A Preliminary Version of the SWP and LWR Calibration; and III. Timing Error in the Mechanism used to make short exposures on bright stars. The differences between the calibration in this report and that in memo II. are:

1. A common flux scale was chosen for the OAO-2 and TD-1 data, while the earlier calibration in memo II used the OAO-2 scale. The change in the OAO-2 fluxes is given in the top panel of Figure 3, amounting to as much as a 20% decrease in those fluxes near 1500Å. The other panels compare the chosen scale to other UV flux determinations and are typically within ± 10%.

2. The ITF curves, which remove the non-linearities in the vidicon cameras, were refined. This caused changes in extracted FN of ~ ± 10% at different wavelengths.

3. The data extraction program was changed from the COMPARE version to the EXTLOW version. This allowed low dispersion data to be extracted the same way as is done in high dispersion, where an artificial slit samples the data along the spectrum in the original image, and also permits the flagging of the reseaux. Extracted EXTLOW FN values are about 1.8X those extracted by the program COMPARE from the same image.

4. A timing error in the aperture select mechanism was discovered (see memo III). Spectra timed this way for μ Col were used for the earlier calibration. This error should cause fluxes to be derived that are ~ 20% low for SWP and ~ 15% low for LWR when using the memo II calibration, since the μ Col exposures were on the order of 1 sec.

R. Bohlin

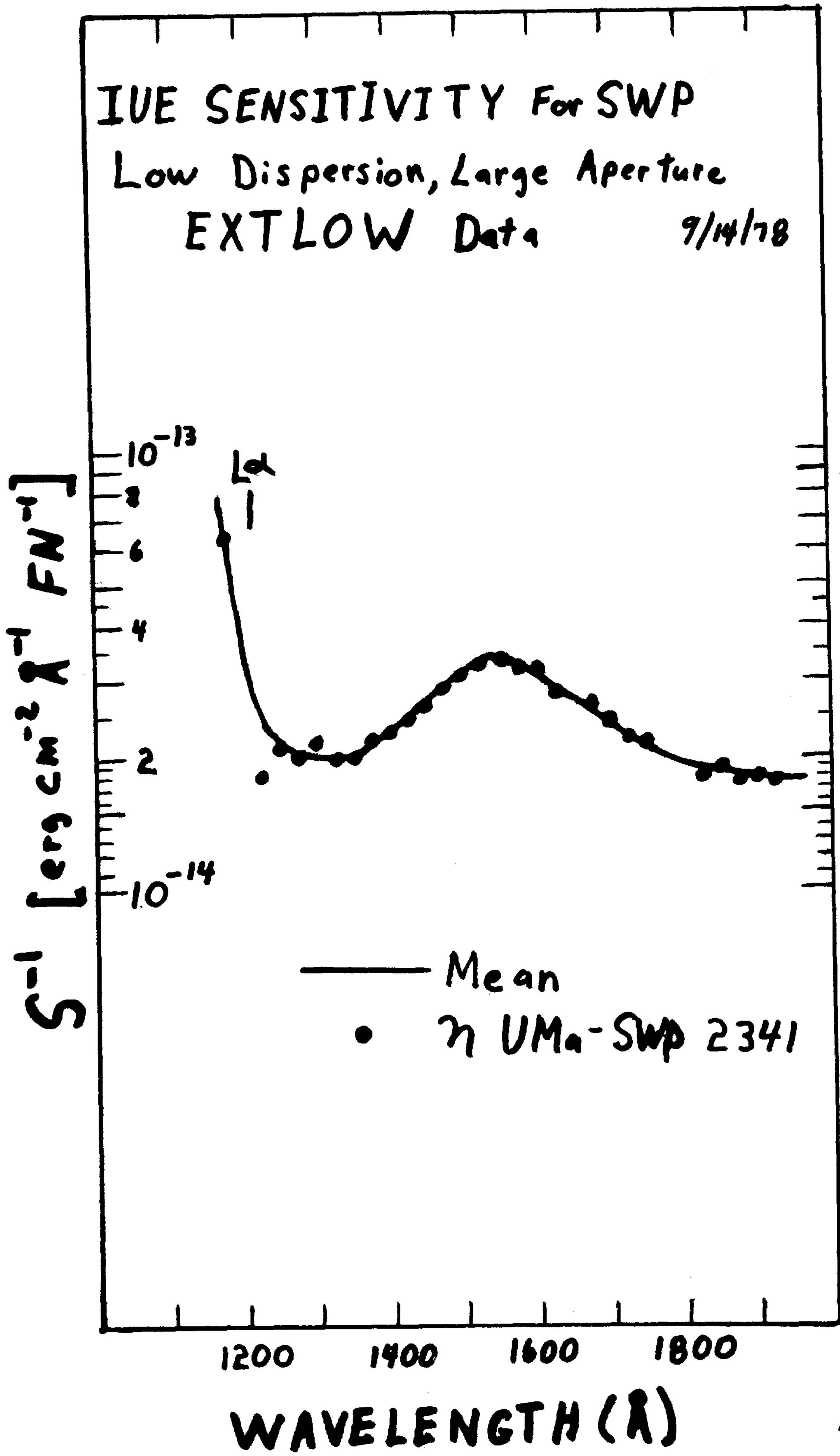
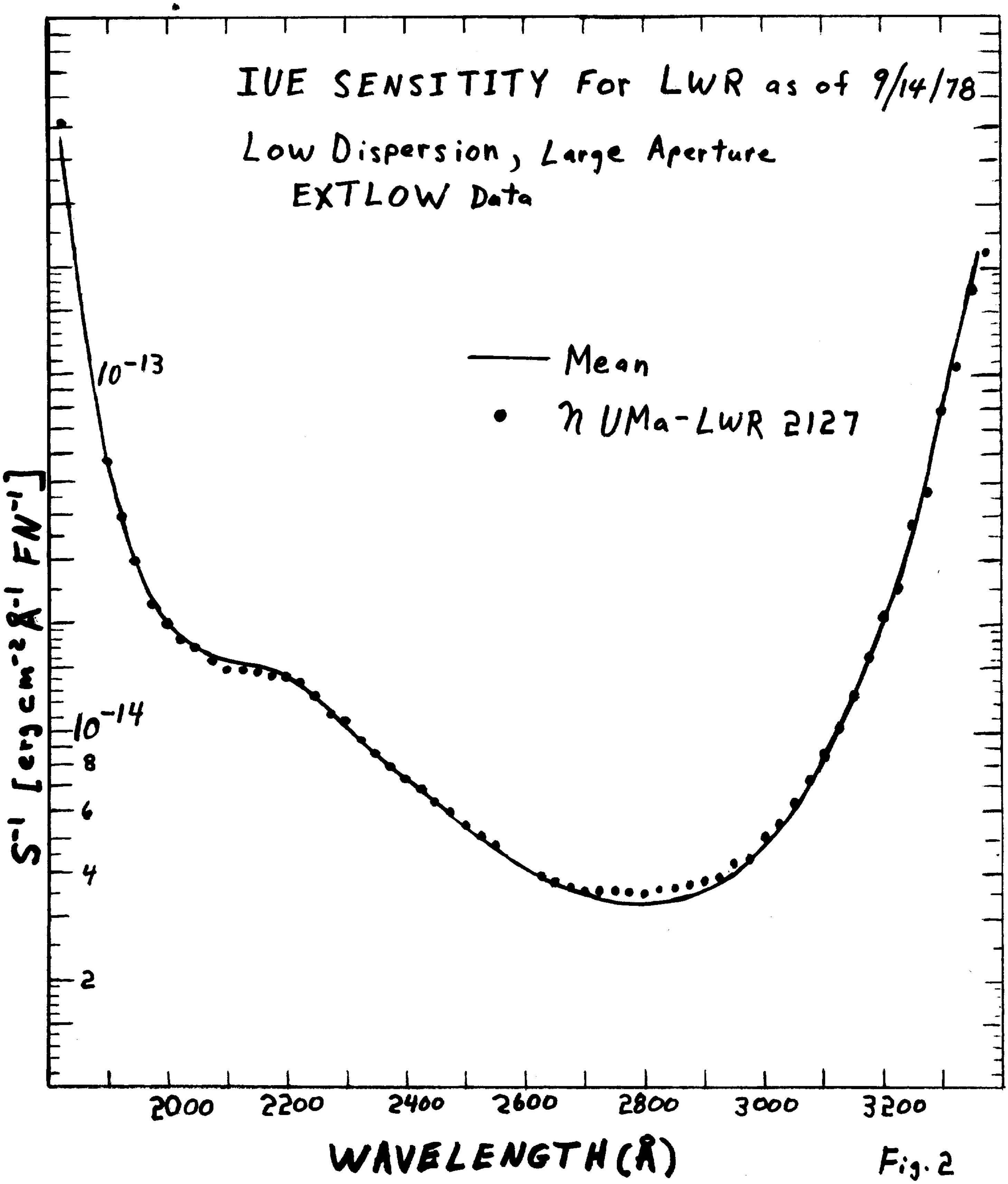
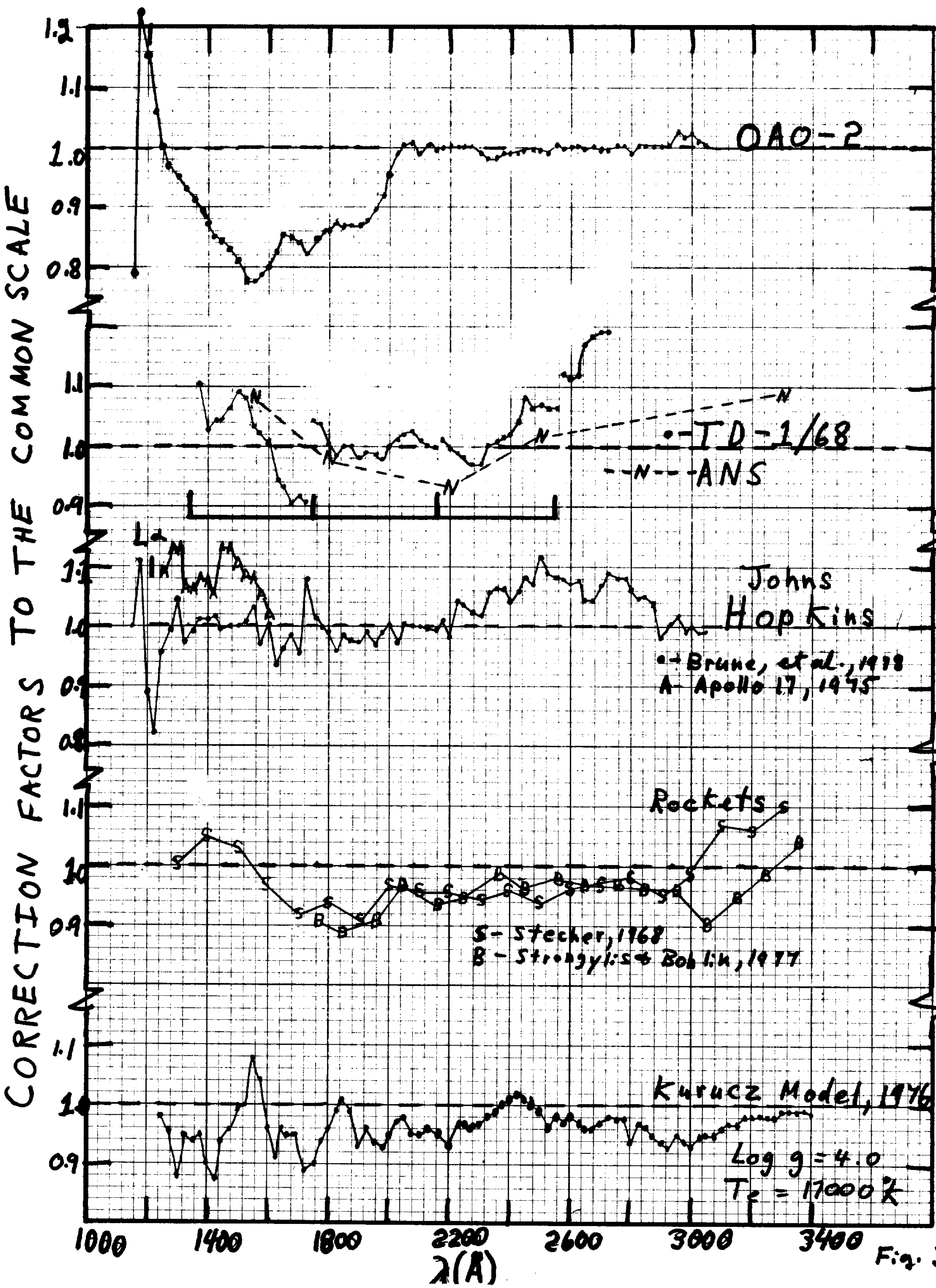

IUE SENSITIVITY For SWP
Low Dispersion, Large Aperture
EXTLOW Data
9/14/78
S^{-1} [erg cm^{-2} $Å^{-1}$ FN^{-1}]
10^{-13}
8
6
4
2
1.0^{-14}
Lα
Mean
η UMa-SWP 2341
1200
1400
1600
1800
WAVELENGTH (Å)

Fig. 1



IUE SENSITITY For LWR as of 9/14/78
Low Dispersion, Large Aperture
EXTLOW Data
Mean
η UMa-LWR 2127
10^{-13}
10^{-14}
8
6
4
2
S^{-1} [erg cm^{-2} Å^{-1} FN^{-1}]
2000
2200
2400
2600
2800
3000
3200
WAVELENGTH (Å)

Fig. 2



CORRECTION FACTORS TO THE COMMON SCALE
OAO-2
TD-1/68
ANS
Johns Hopkins
Brune, et al., 1978
A- Apollo 17, 1975
Rockets
S- Stecher, 1968
B - Strongylis & Bohlin, 1977
Kurucz Model, 1976
Log g = 4.0
Te = 17000 K
λ(Å)
1000
1400
1800
2200
2600
3000
3400

Fig. 3

PHOTOMETRIC CALIBRATION OF IUE

9/14/78

V. How Reproducible are the Low Dispersion Spectra When Making Repeated Observations of the Same Star?

The answer to this question depends on the bandpass, the time scale, and the signal level. The discussion here is of well exposed spectra between ½ and full scale. Reproducibility of underexposed spectra should be studied separately, in conjunction with tests of the ITF's for linearity. The point to point noise level in parts of well-exposed high-dispersion spectra has been reported on by Boggess, Bohlin, et al. 1978 in Nature and is 2 to 3%, approaching the theoretical quantum limit. However, when low dispersion spectra are averaged in 25Å bins and intercompared from one image to another separated in time by several days, the reproducibility is on the order of 10%, consistent with the scatter found in the absolute calibration. Figures 1 and 2 illustrate the ratio of later spectra to the first SWP and LWR spectrum of HD60753. Neither the apparent noise nor the trends are well understood. Errors in the wavelength scales were not removed, but alignment of the spectra in wavelength should not be a problem except shortward of 1250Å where the SWP response function is steep, as illustrated by the smooth denominator used for the ratios in the bottom panels of Figures 1 and 2.

In order to minimize the effect of any possible random noise, the low dispersion spectra were averaged in larger bandpasses of 300Å centered at 1400 and 1700Å for SWP and of 600Å centered at 2150 and 2750Å for LWR. Figure 3 and 4 illustrate the repeatability in these broad bands for standard stars observed between day 80 and day 216, 1978. All data are compared to the first observation of a standard star in the large aperture, which is represented by the point at unity on the day of observation. Filled symbols represent the shorter wavelength bandpass, and the open symbols the longer wavelength in each observation. Each relative sensitivity value is defined as:

$$\frac{FN/t}{FN_o/t_o} = \frac{R}{R_o},$$

where the FN is the broadband mean IUE Flux Number, t is the exposure time, R is called the response, and the denominator is the initial response to the star. For example, the star HD60753 (circles) was observed over the longest baseline and showed a maximum deviation from the initial response at 1700Å in the large aperture of 14% on days 197 and 216 in Figure 3.

The points for the small apertures in the lower panels of Figures 3 and 4 represent the fraction of light passing through the small 3 arcsec aperture, relative to R_o. In addition, the relative location of the open and filled symbols define the deviation in the slope of the response of the small aperture spectrum with respect to the large aperture spectrum. The messy Figures 3 and 4 are difficult to summarize, but that is attempted in the following Table.

The causes for the observed changes in repeated stellar photometry are obscure. Some possibilities are:

1. Variability in the stellar sources. This seems unlikely because all stars observed repeatedly show some variability, and because the wavelength dependent variations are <u>not</u> obviously correlated between large and small aperture spectra obtained on the same image.

2. Fundamental limit on vidicon camera stability. A good possibility, but again one might expect the wavelength dependent changes of the large and small aperture spectra on the same image to correlate better than observed.

3. Resampling and smoothing done in the GEOM step of the data reduction. A smoothing is performed to geometrically correct the image using the original, non-linear data. The size of the error introduced by this procedure is unknown, but it could be a variable amount due to variations in telescope focus or to slight differences in the sampling of the original image during the tube readout.

4. Null Variation

5. Residual High Disp. Images

Ralph Bohlin

SUMMARY

IUE PHOTOMETRIC REPEATABILITY FROM DAY 80 TO 216, 1978

	SWP		LWR	
BROAD BAND (300, 600 Å)	%	(# OF SPECTRA)	%	(# OF SPECTRA)
MAXIMUM CHANGE IN RESPONSE	14	(19)	11	(17)
ONE SIGMA SCATTER IN RESPONSE	±3	(19)	±3	(17)
MAXIMUM CHANGE IN SLOPE	11	(16)	12	(19)
ONE SIGMA SCATTER IN SLOPE	±4	(16)	±4	(19)
MAXIMUM CHANGE IN RESPONSE ON THE SAME DAY (LARGE - APER)	4	(2)	2	(3)
MAXIMUM CHANGE IN SLOPE ON THE SAME DAY (SMALL - APER)	10	(3)	12	(6)
NARROW BAND (25 Å)				
ADDITIONAL SCATTER WITHIN BROAD BANDS	±4	(4)	±5	(4)
ESTIMATED ERROR [ALL VALUES]	1		1	

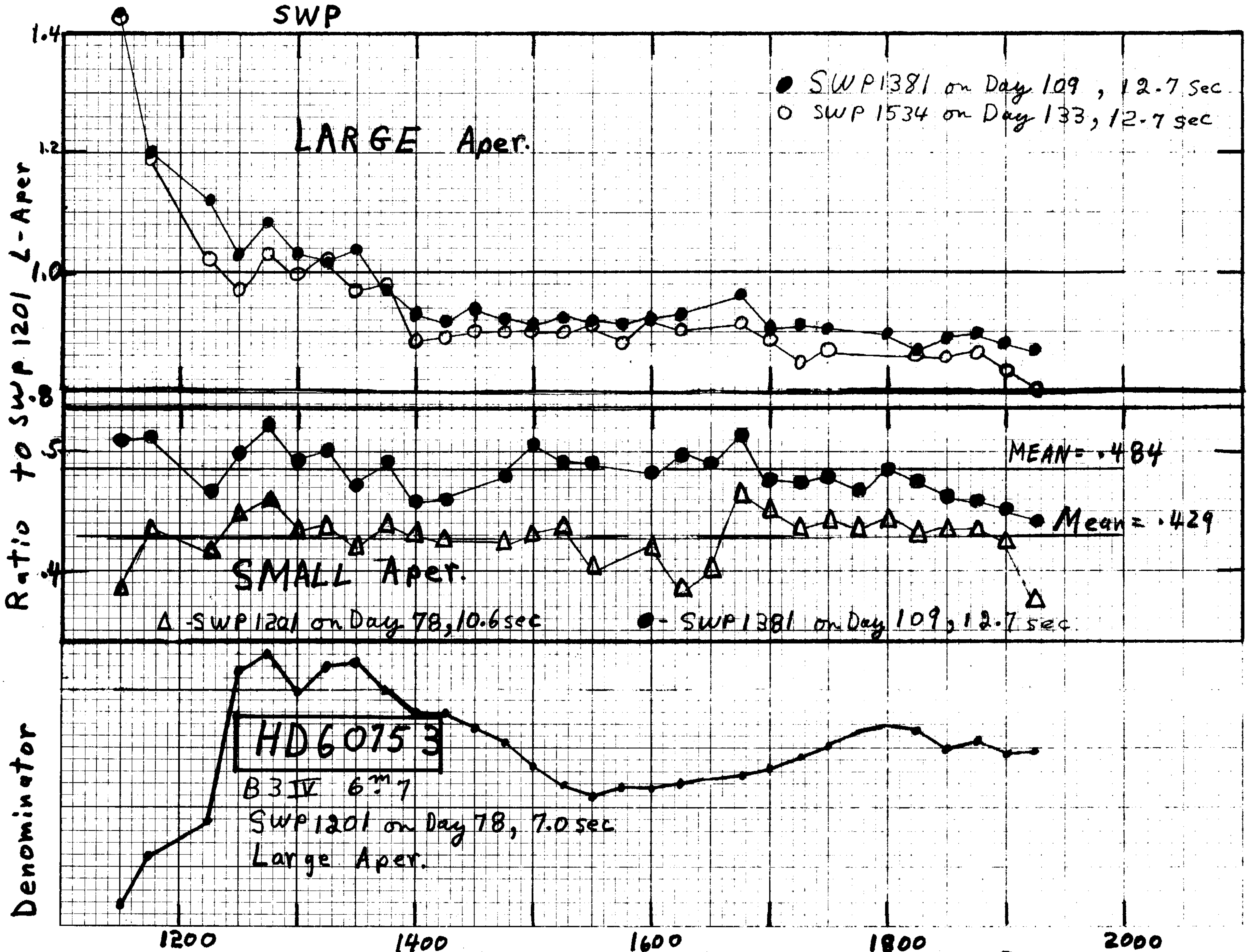
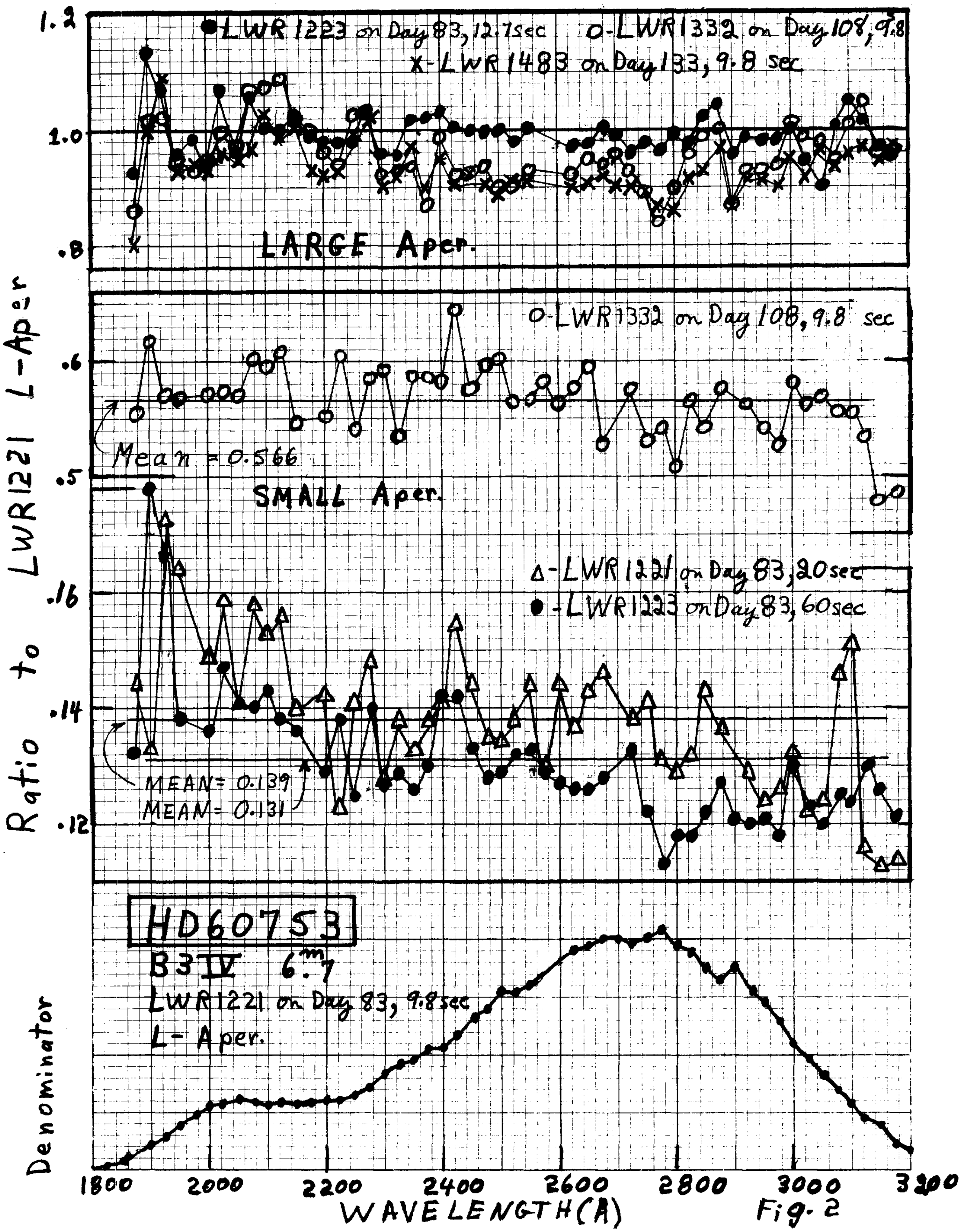
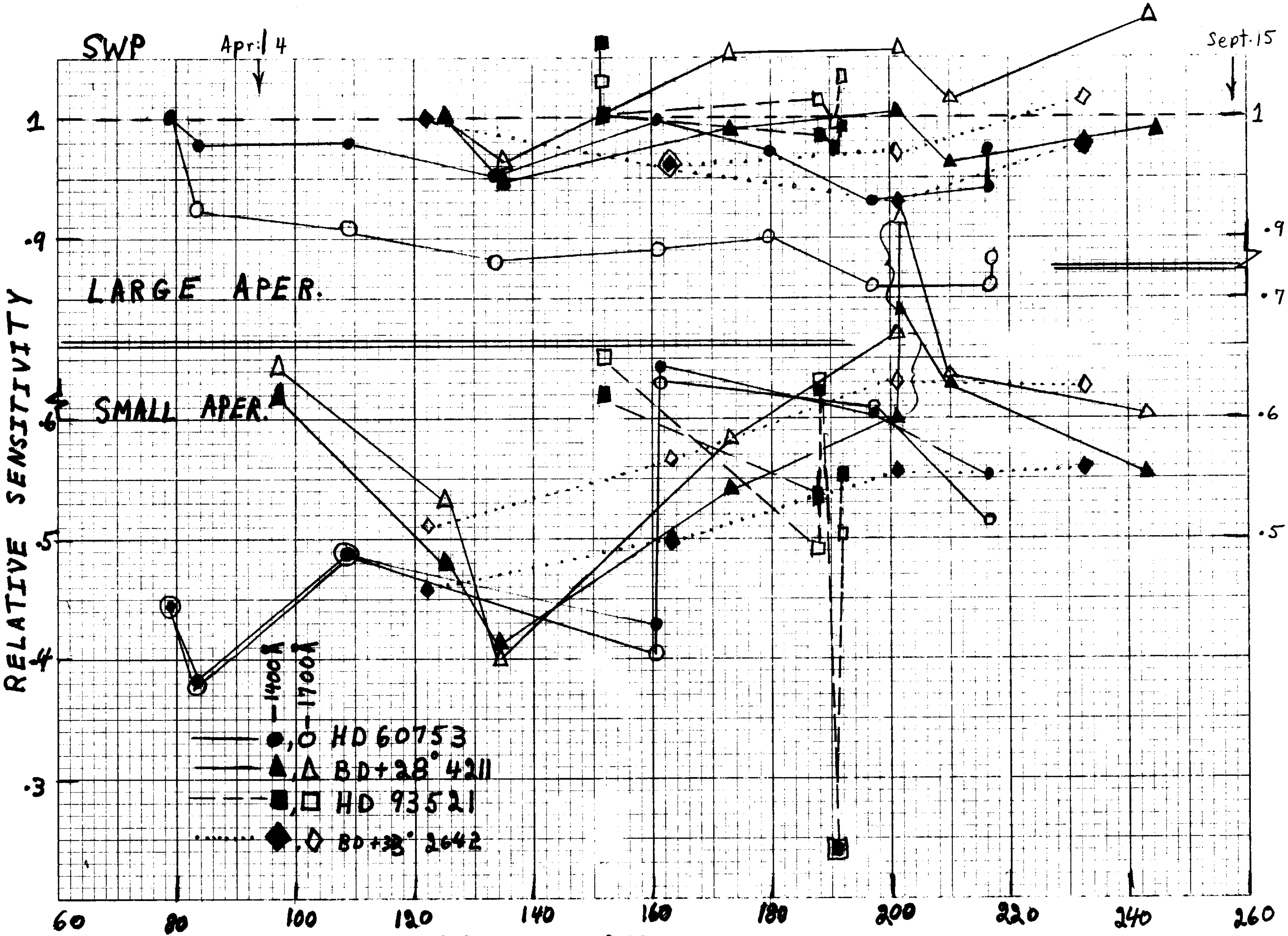

SWP
LARGE Aper.
● SWP1381 on Day 109, 12.7 sec
O SWP 1534 on Day 133, 12.7 sec
MEAN = .484
Mean = .429
SMALL Aper.
Δ - SWP1201 on Day 78, 10.6 sec
● - SWP1381 on Day 109, 12.7 sec
HD60753
B3IV 6.m7
SWP1201 on Day 78, 7.0 sec
Large Aper.
Ratio to SWP 1201 L-Aper
Denominator
1.4
1.2
1.0
.8
.5
.4
1200
1400
1600
1800
2000
WAVELENGTH (Å)

Fig. 1



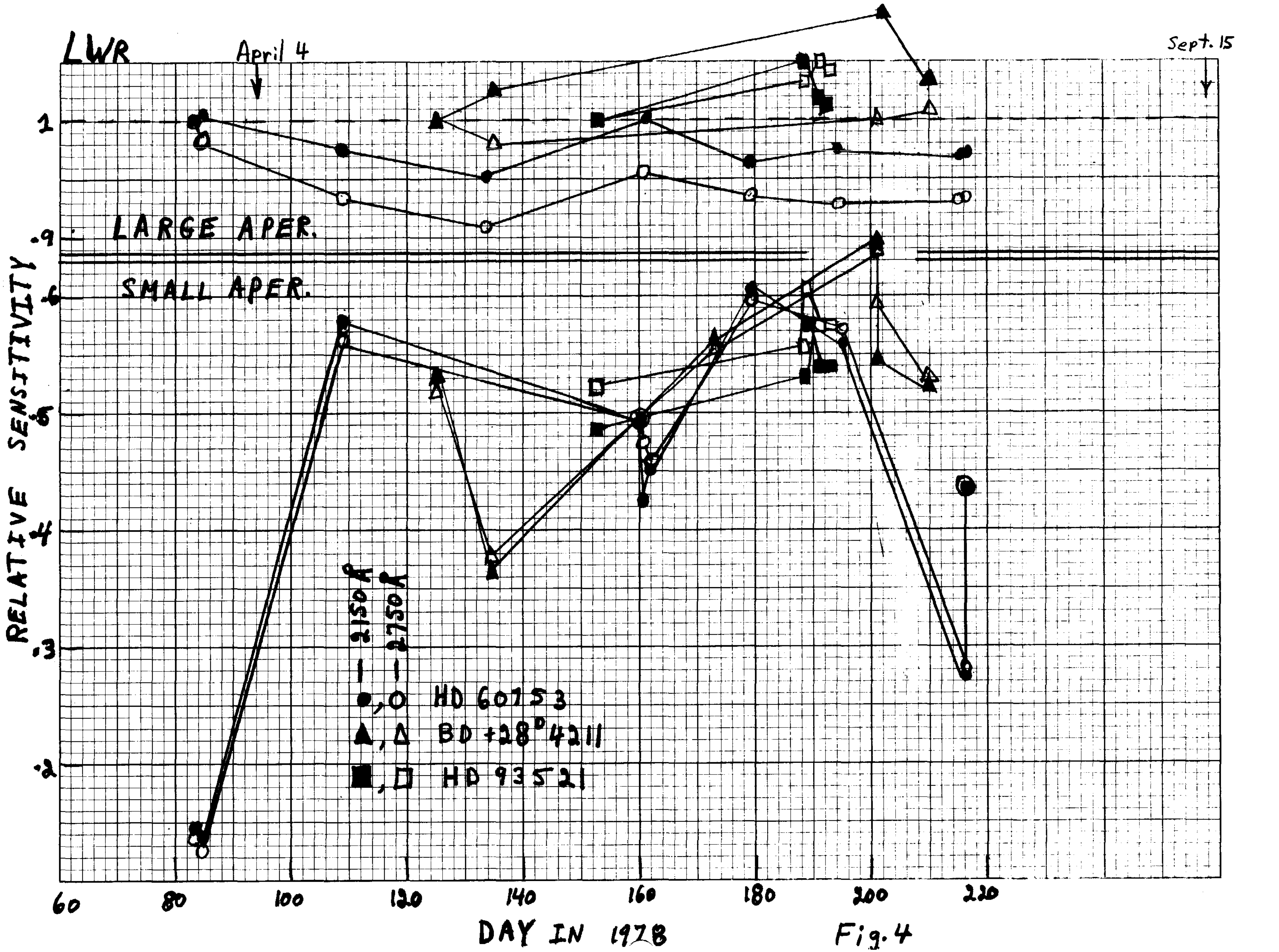
1.2
1.0
.8
●LWR 1223 on Day 83, 12.7sec
O-LWR 1332 on Day 108, 9.8
X-LWR 1483 on Day 133, 9.8 sec
LARGE Aper.
O-LWR 1332 on Day 108, 9.8 sec
.6
.5
Mean = 0.566
SMALL Aper.
Δ-LWR 1221 on Day 83, 20sec
●-LWR 1223 on Day 83, 60sec
.16
.14
.12
MEAN = 0.139
MEAN = 0.131
Ratio to LWR1221 L-Aper
HD60753
B3IV 6.^{m}7
LWR 1221 on Day 83, 9.8 sec
L-Aper.
Denominator
1800
2000
2200
2400
2600
2800
3000
3200
WAVELENGTH (Å)

Fig. 2



SWP
April 4
Sept. 15
LARGE APER.
SMALL APER.
RELATIVE SENSITIVITY
1
.9
.7
.6
.5
.4
.3
60
80
100
120
140
160
180
200
220
240
260
DAY in 1978
—1400Å
—1700Å
●,○ HD 60753
▲,△ BD+28° 4211
■,□ HD 93521
◆,◇ BD+33° 2642

Fig. 3



LWR
April 4
Sept. 15
LARGE APER.
SMALL APER.
RELATIVE SENSITIVITY
1
.9
.6
.5
.4
.3
.2
2150 Å
2750 Å
●,○ HD 60753
▲,△ BD +28° 4211
■,□ HD 93521
60
80
100
120
140
160
180
200
220
DAY IN 1978

Fig. 4

PHOTOMETRIC CALIBRATION OF THE IUE

VI. Joint US/UK/ESA Calibration for Low Dispersion Large Aperture

The calibration of the IUE scientific instrument provided here is based on a comparison between IUE measurements and data from the ANS, OAO-II and TD1 S2/68 satellite experiments for about 12 stars. Most of these stars were repeatedly observed by IUE since 3 April 1978.

All data from other satellites were reduced to a common scale using the methods outlined in the IUE Calibration Memo IV.

Over the past half year, no long term drifts in sensitivity occurred to a $\pm$ 10% accuracy.

The shape of the mean sensitivity curve is well defined. The rms error in the results from individual stars is typically 5% or less for $1250 < \lambda < 2000$Å for the SWP camera and for $2050 \leq \lambda < 3000$Å for the LWR camera.

For $\lambda \gtrsim 3050$Å additional stability problems may exist, which are at present being analyzed, and the calibration for this wavelength range should be treated with caution.

For the small aperture, the sensitivity has the same wavelength dependence as for the large aperture. However, only relative fluxes can be obtained from small aperture data as the transmission of this aperture varies from 30 to 70%.

Data processed with program COMPARE instead of EXTLOW can be reduced with the calibration presented here but a correction factor 0.56 has to be included:

$$S_\lambda^{-1}\ (\text{COMPARE}) = S_\lambda^{-1}\ (\text{EXTLOW})/0.56.$$

An additional error of $\sim\pm$ 15% should be associated with the COMPARE data because of the preliminary ITF used.

IUE flux numbers (FN) are related to fluxes by

$$F_\lambda = S_\lambda^{-1} * FN/t$$

where t is the exposure time in seconds.

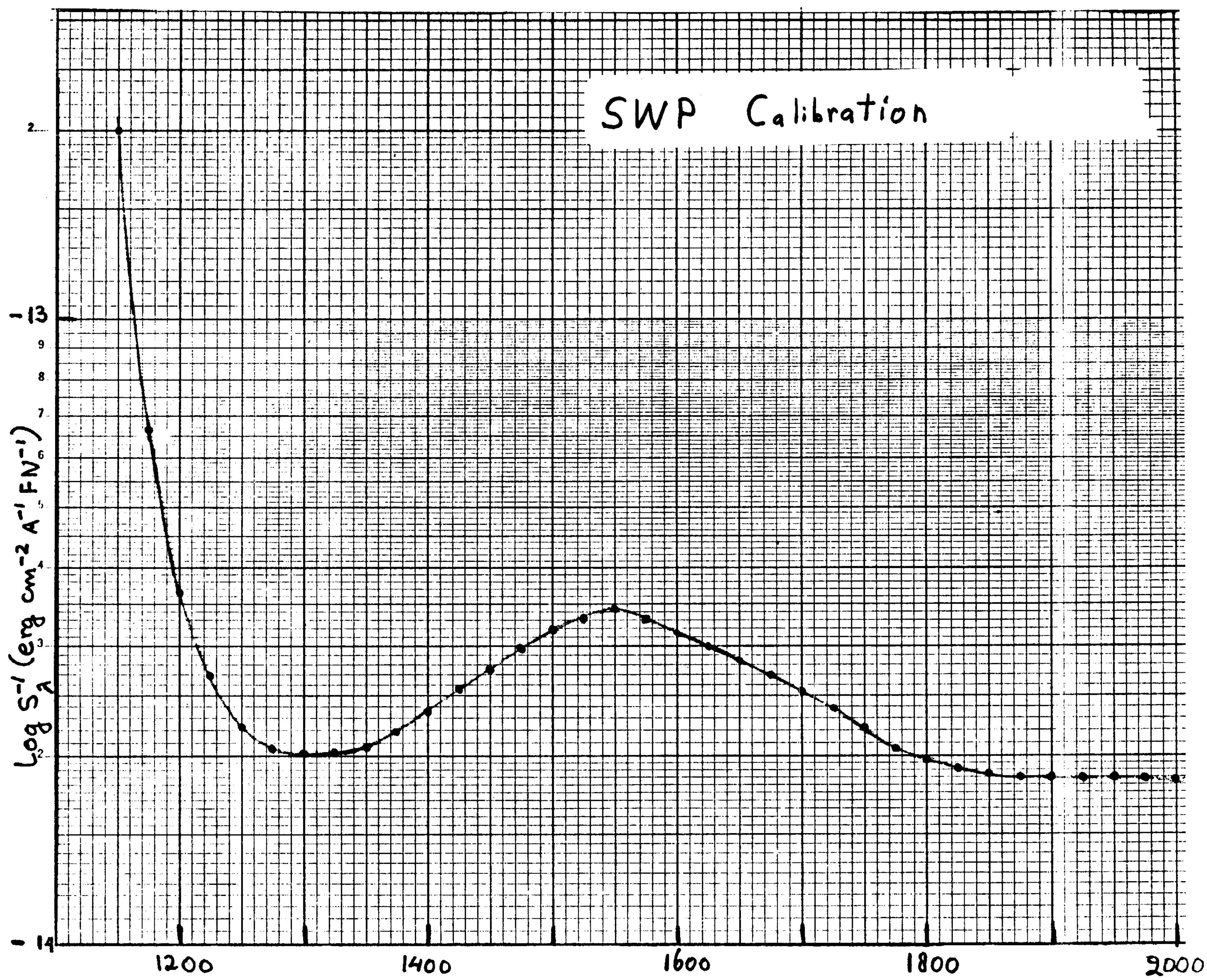
As many guest observers are analyzing IUE results now, this memo is distributed before a comprehensive report is available. A complete description of the calibration methods is in preparation and will be made available as soon as possible.

Ralph C. Bohlin

M. A. J. Snijders

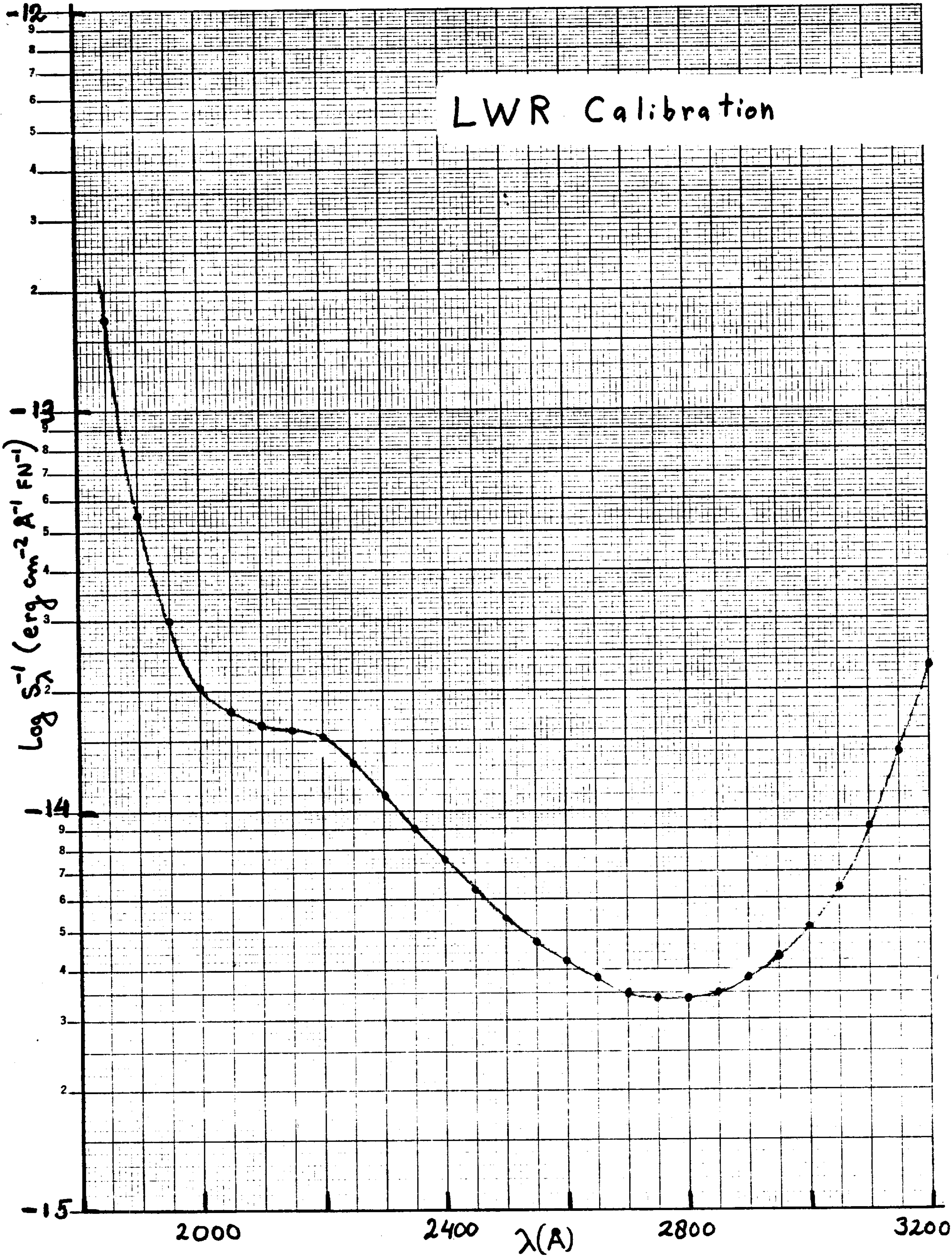
SWP CALIBRATION FOR LOW DISPERSION DATA EXTRACTION PROGRAM EXTLOW

λ (Å)	S^{-1} (10^{-14} erg cm^{-1} $Å^{-1}$ FN^{-1}) UK/ESA	US	Mean
1150	21.5:		20.0:
1175	7.15	6.4	6.65
1200	4.14	3.4	3.65
1225	2.93	2.55	2.68
1250	2.30	2.19	2.23
1275	2.03	2.07	2.06
1300	2.02	2.02	2.02
1325	2.04	2.01	2.03
1350	2.11	2.05	2.07
1375	2.25	2.16	2.19
1400	2.41	2.34	2.36
1425	2.62	2.53	2.56
1450	2.84	2.70	2.75
1475	3.07	2.92	2.97
1500	3.28	3.15	3.19
1525	3.38	3.3	3.33
1550	3.49	3.4	3.43
1575	3.39	3.27	3.31
1600	3.27	3.10	3.16
1625	3.18	2.91	3.00
1650	3.05	2.75	2.85
1675	2.95	2.61	2.70
1700	2.77	2.46	2.53
1725	2.54	2.31	2.39
1750	2.30	2.18	2.22
1775	2.08	2.04	2.05
1800	2.00	1.95	1.97
1825	1.94	1.89	1.91
1850	1.92	1.84	1.87
1875	1.90	1.82	1.85
1900	1.92	1.80	1.84
1925	1.96	1.79	1.84
1950	1.95	1.78	1.84
1975	1.95	1.77	1.83
2000	1.96		1.83


SWP Calibration
Log S_λ^{-1} (erg cm^{-2} A^{-1} FN^{-1})
-13
-14
1200
1400
1600
1800
2000

LWR CALIBRATION FOR LOW DISPERSION DATA EXTRACTION PROGRAM EXTLOW

λ (Å)	S^{-1} (10^{-14} erg cm^{-2} Å^{-1} FN^{-1}) US	UK/ESA	Mean
1850	17.5	16.5	17.0:
1900	5.5	5.5	5.5
1950	2.8	3.2	3.0
2000	1.95	2.15	2.04
2050	1.69	1.85	1.77
2100	1.58	1.72	1.65
2150	1.51	1.70	1.61
2200	1.42	1.67	1.54
2250	1.22	1.44	1.32
2300	1.02	1.18	1.10
2350	.85	.96	.90
2400	.73	.79	.76
2450	.63	.63	.63
2500	.54	.54	.54
2550	.47	.47	.47
2600	.415	.42	.42
2650	.375	.385	.38
2700	.345	.355	.35
2750	.33	.36	.34
2800	.328	.36	.34
2850	.333	.375	.35
2900	.36	.40	.38
2950	.40	.45	.43
3000	.48	.54	.51
3050	.60	.68	.64
3100	.86	.98	.91
3150	1.26	1.5	1.4
3200	2.10	2.5	2.3:
3250	3.65	4.5	4.2:
3300	8.4	9.4	8.9:
3350	18.2:		19:



LWR Calibration
Log S_λ^{-1} (erg cm^{-2} Å^{-1} FN^{-1})
-12
-13
-14
-15
2000
2400
2800
3200
λ(Å)