General Disclaimer

One or more of the Following Statements may affect this Document

- This document has been reproduced from the best copy furnished by the organizational source. It is being released in the interest of making available as much information as possible.

- This document may contain data, which exceeds the sheet parameters. It was furnished in this condition by the organizational source and is the best copy available.

- This document may contain tone-on-tone or color graphs, charts and/or pictures, which have been reproduced in black and white.

- This document is paginated as submitted by the original source.

- Portions of this document are not fully legible due to the historical nature of some of the material. However, it is the best reproduction available from the original submission.

Produced by the NASA Center for Aerospace Information (CASI)

NASA

Technical Memorandum 78035

ABSOLUTE CALIBRATION
IN THE 1750-3350 Å REGION

G. J. Strongylis and R. C. Bohlin

NOVEMBER 1977

ABSOLUTE CALIBRATION IN THE
1750 - 3350 Å REGION

G. J. Strongylis*

and

R. C. Bohlin

Code 681

Goddard Space Flight Center

Greenbelt, Maryland 20771

*Also University of Maryland, Astronomy Program

ABSTRACT

The absolute flux measurements in the rocket ultraviolet made by Bohlin, Frimout, and Lillie (BFL) are revised using a more correct treatment of the air extinction that enters the air calibration of their instrument. The absorption by molecular oxygen and ozone, Rayleigh scattering, and extinction by aerosols is tabulated for general use in ultraviolet calibrations performed in air. The revised absolute flux of η UMa and final fluxes for α Lyr and ζ Oph are presented in the 1750-3350 Å region. The absolute flux of the star η UMa (B3V) is compared to four other independent determinations in the 1200-3400 Å region and a maximum difference of 35% is found near 1500 Å between the OAO-2 and Apollo 17 fluxes. Longward of 1700 Å the typical scatter in the different determinations is only $\pm$ 5%. The rocket measurements of BFL, the ANS and TD-1 satellite data, and the Apollo 17 data are compared to the ultraviolet fluxes from the OAO-2, demonstrating a photometric reproducibility of about $\pm$ 3 percent. Therefore, all four sets of spectrophotometry can be reduced to a common absolute scale.

I. Introduction

The simplest way to measure the flux distribution of an astronomical object is by comparing to a standard star with a known spectral energy distribution. This is true for observations from above the earth's atmosphere, as well as for ground based measurements. Historically, absolute flux measurements of stars in the rocket ultraviolet were not reproducible to much better than a factor of two. Since about 1970, the absolute reference standards improved with the introduction of the standard NBS photodiode (Canfield, Johnston, and Madden 1973) and the use of synchrotron radiation by the Wisconsin group (Bless, Code and Fairchild 1976) and also by Bridges et al. (1977). Currently, there are 5 independent flux determinations that show a maximum difference in the flux of η UMa of 35 percent between 1200 and 3400 Å. In addition, blanketed model atmospheres with reasonable effective temperatures of ∿ 17,000 K fall near the mean of these 5 measurements. Any isolated measurements that differ significantly from this data set must be in error.

However, all of the spectrophotometry must be critically evaluated to avoid the possibility of a bandwagon effect, which could occur if experimenters seek only those errors that bring their results into line with the crowd. The history of the reduction of the data on η UMa from Aerobee 13.004 illustrates this danger. Before the flux values in Bohlin, Frimout, and Lillie (1974, referred to as BFL) were published the original reduction was compared to a model atmosphere. A discrepancy of up to 40 percent was found, the source was sought, and a problem was discovered with the prime NBS standard photodiode. A newer photodiode with a more uniform cathode was used to obtain the fluxes published in BFL. This flux distribution for η UMa had the same slope as that of the early results from the Wisconsin group (Bless, Fairchild and Code 1972) but was systematically about 20 percent higher. Subsequently, an error

in the preliminary reduction of the Wisconsin data was found, which increased the flux values by $\sim$ 12 percent, Bless, et al. (1976). These flux values from a rocket flight provide the basis for the calibration of all OAO-2 data in Code and Meade (1976).

This paper presents a second correction to the calibration of BFL, and this is the third time that a revision has brought the OAO-2 flux scale and the BFL measurements into better agreement. The necessity for change in the fluxes of Aerobee 13.004 arises because the prime calibration was done in air over a 73m path. Air extinction is significant and was estimated from the Rayleigh scattering cross section and the O_2 and O_3 absorption cross sections. Since the publication of BFL, total air extinction coefficients and better O_2 absorption cross sections were discovered in the literature. § II discusses the calibration revisions and § III compares the results to other independent flux measurements. In § III, the final fluxes are compared to other modern photoelectric measurements.

II. Correction of the Aerobee 13.004 Calibration

The rocket payload is described in BFL. For point sources, the most direct calibration procedure is to use collimated light of known absolute flux for the calibration source. The spectrometer was calibrated using a National Bureau of Standards tungsten ribbon filament lamp, number Q17, down to about 2400 $\overset{\circ}{A}$. The lamp was located 73m from the payload in order to approximate a point source adequately. For shorter wavelengths, the vacuum calibration was relative to an NBS photodiode.

In order to obtain the instrumental calibration from the tungsten lamp, the amount of atmospheric extinction must be determined. For air near the earth's surface, three factors contribute to the attenuations: absorption by gases, Rayleigh scattering by air molecules, and extinction from air-born dust particles (aerosols). Hudson (1974) reviews critically the experimental results for the published cross sections of atmospheric molecules.

A) Absorption by Molecular Oxygen

Experimentally, the absorption cross section $\sigma(\lambda)$ at wavelength λ for molecular species is calculated from the Lambert-Beer law for low pressure measurements.

$$\sigma(\lambda) = \frac{1}{nL} \ln \frac{I(0,\lambda)}{I(P,\lambda)} \tag{1}$$

where:

$I(0,\lambda)$ = intensity transmitted at zero pressure

$I(P,\lambda)$ = intensity transmitted at pressure P.

L = path length (cm)

$$n = n_o \left(\frac{P}{P_o}\right) \left(\frac{T_o}{T}\right) \tag{2}$$

$n_o = 2.687 \times 10^{19}$ cm^{-3} at $T_o = 273.2$K, $P_o = 1$ atm. For O_2, equation (1) is valid up to $P \sim 400$mm Hg (Hasson and Nicholls 1971.)

Above 400mm Hg the cross section σ_{O_2} calculated from (1) increases significantly with pressure, i.e. the Lambert-Beer law is not obeyed. The results

4

can be represented by an expression of the form

$$\sigma(P) = \sigma_0 + \beta P \quad , \tag{3}$$

where σ_0 is the cross section at zero pressure and β is the rate of change with the pressure. Ditchburn and Young (1962) ascribe this effect to the creation of O_4 as the pressure increases. Shardanand (1969) studied this problem, but his data will not be used here because of an error in his pressure measurements, as noted by Hudson (1974).

For the Schumann-Runge system of absorption bands between 1750 and 2100 $\overset{o}{A}$, Hudson recommends the data of Ogawa (1971). For the Herzberg continuum between 2100 and 2400 $\overset{o}{A}$, he recommends Ogawa (1971) and Ditchburn and Young (1962), who take into account the pressure effect. Figure 1 shows the experimental cross sections σ_{O_2} (P=1 atm) as a function of λ, as well as the adopted curve used for the values in Table 1. The results of Blake et al. (1966) for a limited wavelength range are also included. Hudson (1974) prefers the data of Hasson and Nicholls (1971) for the range longward of 2300 $\overset{o}{A}$. However σ_{O_2} (P-1 atm) cannot be deduced from their results, because their study pertains only to the low pressure limit.

A major problem in all measurements of O_2 cross sections is the formation of ozone as a result of the dissociation of molecular oxygen in the absorption cell. Ozone has a maximum cross section of 10^{-17} cm^2 at 2550 $\overset{o}{A}$. Thus, small amounts can have a large effect on the measured O_2 cross sections. Ditchburn and Young (1962) prevented the buildup of O_3 by continually streaming the oxygen through their cell. They were successful, since there was no measurable absorption at 2550 $\overset{o}{A}$.

The major revision of the O_2 cross sections used for the extinction correction in BFL is due to their pressure dependence. The use of the cross sections at 1 atm instead of the cross sections at zero pressure used by

5

BFL increases the absorption due to O_2 by a factor of two. This corresponds to an increase of the total extinction coefficient k_{Tot} by about the same factor in the 1800 to 2400 Å range where O_2 absorption dominates.

B) Absorption by Ozone, O_3

The spectrum of ozone can be conveniently divided into two regions: the first is between 1000 and 2000 Å and consists of broad bands overlying a possible continuum (Price and Simpson, 1941). The second region includes the well-known Hartley bands and continuum between 2000 and 3000 Å, and the Huggins bands between 3000 and 3500 Å (Hudson, 1971). In Fig. 3.23a of Robinson (1966) the data of Inn and Tanaka (1953) for the absorption coefficient k_{O_3} are shown to be between those of Ny and Choong (1933) and Vigroux (1953) in the 2000 to 3000 Å region. There is a maximum difference of 8 percent between the data of Inn and Tanaka (1953) and the other data at the peak of absorption near 2550 Å. In addition, there is agreement within 2 percent between the values of Inn and Tanaka (1953) and those of Griggs (1968) except between 2000 and 2100 Å, where Hudson (1974) recommends the values of Inn and Tanaka. The values used in Table 1 are those of Inn and Tanaka and they are pressure independent.

C) Rayleigh Scattering

The Rayleigh scattering cross section σ_R per molecule is independent of the temperature and pressure and is given by Penndorf (1957)

$$\sigma_R(\lambda) = 1.060 \ \frac{32\pi^3}{3n^2} \frac{(\eta - 1)^2}{\lambda^4} \qquad cm^2 \tag{4}$$

where λ is in cm, 1.060 is the depolarization factor, η is the refractive index for air at laboratory conditions, and $n = 2.504 \times 10^{19}$ cm^{-3} is the density, at the laboratory conditions of T = 293 K and P = 1 Atm.

The refractive index for standard temperature and pressure (STP) conditions is from Allen (1973) and is in agreement with the values of Penndorf (1957)

$$\eta_0 - 1 = 2.876 \times 10^{-4} + 1.629 \times 10^{-6} \ \lambda^{-2} + 1.36 \times 10^{-8} \ \lambda^{-4} \tag{5},$$

where λ is in micrometers. Penndorf (1957) shows that the refractive index depends on temperature and pressure according to the formula

$$(n - 1) = (n_0 - 1)\left[\frac{1 + \alpha\, t_0}{1 + \alpha\, t}\right] \frac{P}{P_0} \quad , \tag{6}$$

where $\alpha = 0.00366$. This was used to convert the refractive index at STP, where $t_0 = 0\ ^{\circ}C$, to the laboratory conditions of $t = 20\ ^{\circ}C$ and $P_0 = P = 1$ Atm. Table 1 shows the scattering cross sections σ_R.

D) Total Extinction Including Aerosols

The total atmospheric attentuation is needed in order to obtain the proper BFL calibration. The total extinction coefficient k_{Tot} in units of length^{-1} is defined as

$$k_{Tot} = k_{gases} + k_{aerosols} \tag{7}$$

The contribution of the gases is

$$k_{gases} = \sum_i \sigma_i f_i\, n \quad , \tag{8}$$

where $n = 2.504 \times 10^{19}$ cm^{-3} is the density at $T = 293\ ^{\circ}K$ and $P = 1$ Atm, σ_i is the cross section, and f_i is the concentration of each species, $f_{O_2} = .209$ (Allen, 1973). As measured in the same laboratory a year after the BFL experiment, $f_{O_3} = 1.4 \times 10^{-8}$. This value is on the low side of the variation of ambient ozone concentration of 1×10^{-8} to 1×10^{-7} (Allen, 1973), but is typical for a laboratory, where the ambient air has been filtered (Dunkelman 1977, private communication). For Rayleigh scattering $f_R = 1$. Table 2 shows the individual extinction coefficients and the total contribution of the gases $\sum k_i$ for the laboratory conditions of $t = 20\ ^{\circ}C$ and $P = 1$ atm.

Figure 2 shows k versus wavelength for Rayleigh scattering, Rayleigh plus O_2, and the total of O_2, O_3, and Rayleigh. In addition, the spectral attenuation curve for the visibility of 9 km at ~ 5500 Å (Baum and Dunkelman 1955) is shown. According to Dunkelman (1977, private communication), the interior of a building

7

has an extinction similar to an atmosphere with about 9 km visibility. The visibility is the maximum distance at which high contrast objects can be distinguished by the eye and corresponds to an optical depth of about 4 at 5500 Å. This curve includes the total contribution of the gases and the aerosols.

In order to extend the 9 km Dunkelman curve to wavelengths shortward of 2500 Å we need to know the absorption due to aerosols. The zenith extinction due to aerosols for the atmosphere can be represented by the formula from Siedentopf and Scheffler (1965)

$$E_{aer} = 1.086 \; \beta \; \lambda^{-\alpha} \quad mag \quad , \tag{9}$$

where β is the haze coefficient. The exponent α is determined empirically and is found to vary between 1.0 and 1.5 with the average value of 1.3 (Wempe 1947) adopted here. In order to convert E_{aer} from magnitudes to units of km^{-1} the scale height of aerosols in the atmosphere is needed. The scale height H is independent of wavelength (Elterman 1970), but depends on the visibility. From Elterman's Table 1 we get H = 1.13 km for 9 km visibility. The contribution due to aerosols is then

$$k_{aer} = \frac{E_{aer}}{2.5 \; (log \; e)H} = \frac{\beta}{H\lambda^{1.3}} \quad km^{-1} \tag{10}$$

When this extinction by the aerosols for $\beta = 0.2$ is added to the total contribution of the gases, a smooth continuation of the 9 km Dunkelman curve to shorter wavelengths is obtained. The resulting solid line with symbols in Figure 2 from 1800 to 3350 Å gives our adopted total extinction coefficients k_{Tot}. The total optical depth

$$\tau_{Tot} = k_{Tot} \; L \quad , \tag{11}$$

where L = 0.073 km is the laboratory path length used in the BFL air calibration, and the correction factors $exp(-\tau_{Tot})$ are shown in Table 2.

In the 2450 to 2850 Å region, where an air correction had been made by BFL, the new final correction factors in Table 3 are obtained by dividing the $exp(-\tau_{Tot})$ factors from Table 2 by the old correction factors of BFL. In

the 2950 to 3350 Å region, the final correction factors are the same
as in Table 2, because there was no air correction made in BFL.

BFL normalized the vacuum calibration to the tungsten lamp calibration
at ∿ 2400 Å because of probable loss of light at the entrance aperture of
the flight spectrometer during the vacuum calibration. A comparison of the
final tungsten sensitivity curve to the old curve of BFL gives a correction
factor of 0.83 at 2400 Å that is applied to the fluxes of BFL from 1750
to 2350 Å. The normalization is done at 2400 Å, because shortward of
2400 Å the uncertainty in the tungsten lamp calibration rapidly increases
and longward of 2400 Å there is no vacuum calibration data.

Since the relative fluxes between 1750 and 2350 Å are still based on the
NBS diode, any changes to the NBS ultimate standard should also be included.
However, no correction is made for the NBS change of base between 1973 and
1977, because those differences are all less than 3% in the region of interest
(Canfield 1977, private communication). Table 3 contains the correction factors
for the BFL calibration and the final fluxes for the stars η UMa, α Lyr
and ζ Oph.

E) Error Analysis

The following sources of error affect the determination of the flux.
(1) The NBS lamp has an uncertainty of 6% at 2250 Å that decreases to 3%
at 3000 Å; errors quoted by NBS for the diode are typically 8%. (2) The
error from the counting statistics in the flight data is 2% at 1750 Å,
1% at 2450 Å, and 9% at 3350 Å. These are for η UMa and ζ Oph. The α Lyr
data is only slightly lower in quality, except at 3350 Å, where the counting
statistics are ± 16%. (3) From the mean difference of the calibrations
from the two tungsten lamps the reproducibility of the calibration data
is estimated at 3%. In the vacuum calibration, the scatter is about 10%.
(4) The vacuum tank calibration has, in addition, a transfer error from

9

the diode to the standard photomultiplier of about 10%. (5) As the lower limit to the air extinction coefficients we adopt the curve resulting from the addition of the total gas extinction to the aerosol extinction computed with equation (10) and the parameters $\beta = 0.10$ and $H = 1.25$ km, corresponding to the "slightly hazy" condition of Siedentopf and Scheffler (1965) and a visibility of about 15 km. As the upper limit, the 2 km visibility Dunkelman curve is used along with the smooth continuation to shorter wavelengths found for $\beta = 0.40$ and $H = 0.84$ km. The 2 km visibility curve was chosen as a conservative upper limit, because conditions this hazy should have been noticeable to the eye when looking down the long hallway used for the calibration. The values for the scale height H are again taken from Table 1 of Elterman (1970). These limiting curves in the extinction coefficient result in errors to the flux of +17, -4% for $\lambda \leq 2450$ Å and +10, -7% at 3050 and 3350 Å. Since the vacuum calibration of BFL was normalized to the air calibration at $\sim$ 2400 Å, the r.m.s. errors of +17, -4% apply at all shorter wavelengths. All the above sources of error combine to give the root mean square errors in Table 4.

III. Comparison with Other Absolute Flux Measurements

Table 3 shows the final flux distributions obtained by applying correction factors to the old fluxes on the BFL scale for the stars η UMa, ζ Oph, and α Lyr. Figure 3 shows this revised flux of η UMa along with the rocket-ultraviolet spectrophotometry of OAO-2 (Code and Meade 1976), Apollo 17 (Henry et al. 1975), TD1-S2/68 (Humphries et al. 1976 and Jamar et al. 1976), Stecher (1968), and the ground based values of Schild et al. (1971) on the Hayes and Latham (1975) scale. Code and Meade (1976) have normalized the long wavelength OAO-2 data to the fluxes of Hayes and Latham. The results of Stecher (1968) assume that the response of fresh sodium salicylate is flat and are shown as averages over 100 Å bandpasses. The result of the new calibration is to lower the BFL flux for η UMa by ∼ 10% so that longward of 1700 Å most of the independent determinations in Figure 3 agree to about ± 5 percent. The maximum difference among the data shown in Figure 3 is 35 percent near 1500 Å. The agreement of the different sets of measurements is often much better than the quoted error bars, indicating that the estimated systematic errors are generally absent. For example, the estimated error for air extinction in Table 4 is rather conservative, and our actual error is probably much smaller. Scatter and transfer errors represent the worst cases, and the NBS calibration may be better than their officially quoted error.

In Figure 4, individual absolute fluxes obtained with Aerobee 13.004, the Astronomical Netherlands Satellite - ANS (van Duinen et al. 1975), TD1-S2/68, and Apollo 17 are compared with the flux of the same star obtained by OAO-2 (Code and Meade, 1976) in order to determine what sets of data are from photometric instruments, i.e. instruments that can give reproducible results. To compute the flux ratios shown, the higher resolution data were averaged over the bandpass of the lower resolution instrument. The ANS data is from Wu (1975, private communication).

The deviation of the points in Figure 4 from unity represents the difference between the absolute fluxes of OAO-2 and the other data. The spread in the ratios for each experiment is a measure of the reproducibility of the data. The Apollo 17 spectrum of ζ Oph (Henry et. al. 1975) has an uncertain background correction and should not be considered (Henry, private communication). The ratios for the other two Apollo 17 stars shown and a fourth star α Gru have a mean scatter of about ± 5 percent. Ratios for the independent measurement of the flux from γ Ori by Hessberg, et al. (1975) are in disagreement with the main four sets of data discussed here with the ratios to OAO-2 from 0.05 at 1250 Å to 1.43 at 2200 Å. A similar problem exists with the fluxes of Evans (1972).

Assuming that all four sets of data above are actually photometric and that Figure 4 represents the differences between their calibrations, the determination of the absolute flux from one star permits corrections of all four sets of photometry to a common absolute scale.

More measurements of absolute flux values are needed, particularly in the 912 to 1700 Å range. For the present, the best estimate of the UV flux

12

of η UMa might be obtained by using a model stellar atmosphere as an interpolating device to fit the points shown in Figure 3 (Strongylis and Bohlin 1977). For effective temperatures near 17000 $^{\circ}$K, neither line-blanketing nor non-LTE effects in the models are a serious problem.

Dr. C. F. Lillie was co-principal investigator on Aerobee 13.004. Dr. D. Frimout participated in all phases of the calibration and flight procedures.

REFERENCES

Allen, C. W. 1973, _Astrophysical Quantities_, 3rd ed., the Athlone Press, London, p. 119.

Baum, W. A. and Dunkelman, L., 1955, _J. Opt. Soc. Amer._, 45, 166.

Blake, A. J., Carver, J. H., and Haddard, G. N. 1966, _J. Quant. Spectrosc. Radiat. Transfer_, 6, 451.

Bless, R. C., Fairchild, T., and Code, A. D. 1972, _The Scientific Results from the Orbiting Astronomical Observatory (OAO-2)_, NASA SP-310, p. 361.

Bless, R. C., Code, A. D., and Fairchild, E. T. 1976, Ap. J., 203, 410.

Bohlin, R. C., Frimout, D., and Lillie, C. F. 1974, _Astron. and Astrophys._, 30, 127.

Bridges, J. M., Ott, W. R., Pitz, E., Schulz, A., Einfeld, D., and Stuck, D. 1977, _Appl. Optics_, 16, 1788.

Canfield, L. R., Johnston, R. G., and Madden, R. P. 1973, _Appl. Optics_, 12, 1611.

Code, A. D., and Meade, M. R. 1976, Wisconsin Astrophysics, No. 30.

Ditchburn, R. W. and Young, P. A. 1962, _J. Atmos. Terr. Phys._, 24, 127.

van Duinen, R. J., Aalders, J. W. G., Wesselius, P. R., Wildeman, K. J., Wu, C. C., Luinge, W. and Snel, D. 1975, _Astron. and Astrophys._, 39, 159.

Elterman, L. 1970, Envir. Res. Paper No. 318, AFCRL-70-0200, U. S. Air Force.

Evans, D. C. 1972, _The Scientific Results from the Orbiting Astronomical Observatory (OAO-2)_, NASA SP-310, p. 347.

Griggs, M. 1968, _J. Chem. Phys._, 49, 857.

Hasson, V., and Nicholls, R. W. 1971, _J. Phys. B. (At. Mol. Phys.)_, 4, 1769.

Hayes, D. S., and Latham, D. W. 1975, _Ap. J._, 197, 593.

Henry, R. C., Weinstein, A., Feldman, P. D., Fastie, W. G., and Moos, H. W. 1975, Ap. J., 201, 613.

Hessberg, H., Niekerke, J., and Stephan, K. H. 1975, _Astron. and Astrophys._, 42, 389.

Hudson, R. D. 1974, _Can. J. Chem._, 52, 1465.

Hudson, R. D. 1971, Rev. Geoph. and Space Phys., 9, 305.

Humphries, C. M., Jamar, C., Malaise, D., and Wroe, H. 1976, Astron. and
   Astrophys., 49, 389.

Inn, E. C. Y., and Tanaka, Y. 1953, J. Opt. Soc. Amer., 43, 870.

Jamar, C., Macau-Hercot, D., Monfils, A., Thompson, G. I., Houziaux, L., Wilson, R.
   1976, Ultraviolet Bright-Star Spectrophotometric Catalogue, ESA SR-27.

Ny, T. Z. and Choong, S. P. 1933, Compt. Rend., 195, 309.

Ogawa, M. 1971, J. Chem. Phys., 54, 2250.

Penndorf, R. 1957, J. Opt. Soc. Amer., 47, 176.

Price, W. C., and Simpson, D. M. 1941, Trans. Faraday Soc., 37, 106.

Robinson, N. 1966, Solar Radiation (New York: Elsevier Publishing Co.) p. 72.

Schild, R., Peterson, D. M., and Oke, J. B. 1971, Ap. J., 166, 95.

Shardanand 1969, Phys. Rev., 186, 5.

Siedentopf, H. and Scheffler, K. 1965, Landolt-Börnstein Tables, (Springer),
   VI/1, p. 51.

Stecher, T. P. 1968, see Hess, W. N., and Mead, G. D., An Introduction to
   Space Science, 2nd ed. (New York: Gordon and Breach), p. 285.

Strongylis, G. J., and Bohlin, R. C. 1977, BAAS, 9, 367.

Vigroux, E. 1953, Ann. Phys. (Paris), [12], 8, 709.

Wempe, J. 1947, Astron. Nachr., 275, 1.

TABLE 1

ABSORPTION CROSS SECTIONS FOR ATMOSPHERIC GASES

λ	σ_{02} $(10^{-24}cm^2)$	σ_{03} $(10^{-17}cm^2)$	σ_R $(10^{-24}cm^2)$
1800	1600	.076	.570
1850	230	.069	.498
1900	52.6	.052	.438
1950	33.0	.041	.388
2000	23.0	.032	.344
2050	19.0	.035	.306
2100	16.5	.054	.274
2150	14.0	.1	.247
2200	11.3	.17	.221
2250	9.0	.27	.201
2300	7.0	.42	.183
2350	5.0	.61	.165
2400	3.2	.8	.150
2450	2.0	.94	.136
2500	1.4	1.08	.125
2550	.75	1.13	.115
2600	.32	1.09	.105
2650	.08	.96	.096
2700		.78	.089
2750		.58	.082
2800		.39	.081
2850		.23	.075
2900		.13	.069
2950			.067
3000			.062
3050			.058
3100			.054
3150			.051
3200			.047
3250			.044
3300			.042
3350			.039

TABLE 2

ABSORPTION COEFFICIENTS AND ATTENUATION FACTORS

λ (Å)	k_{O_2} (km^{-1})	k_{O_3} (km^{-1})	k_R (km^{-1})	Σk_i (km^{-1})	k_{Tot} (km^{-1})	τ_{Tot}	$e^{-\tau}{}_{Tot}$
						(for 73 m path)	
1800	837	.027	1.426	838.	840	-	-
1850	120	.024	1.249	121.	123	-	-
1900	27.5	.018	1.098	28.6	30.1	-	-
1950	17.3	.014	.971	18.3	19.8	-	-
2000	12.0	.011	.862	12.9	14.3	-	-
2050	9.94	.012	.768	10.72	12.10	-	-
2100	8.63	.019	.687	9.34	10.69	-	-
2150	7.33	.035	.616	7.98	9.29	-	-
2200	5.91	.060	.555	6.53	7.80	-	-
2250	4.71	.095	.501	5.31	6.54	-	-
2300	3.66	.147	.459	4.27	5.47	-	-
2350	2.62	.214	.412	3.25	4.41	-	-
2400	1.67	.280	.375	2.33	3.46	.253	.776
2450	1.05	.330	.342	1.72	2.82	.206	.814
2500	.733	.379	.313	1.425	2.50	.183	.833
2550	.390	.396	.287	1.073	2.24	.164	.849
2600	.170	.382	.263	.815	2.03	.148	.862
2650	.040	.337	.242	.619	1.91	.139	.870
2700		.273	.223	.496	1.86	.136	.873
2750		.203	.207	.410	1.78	.130	.878
2800		.137	.201	.338	1.74	.127	.881
2850		.081	.187	.268	1.67	.122	.885
2900		.046	.174	.220	1.64	.120	.887
2950			.167	.167	1.60	.117	.890
3000			.156	.156	1.58	.115	.891
3050			.145	.145	1.55	.113	.893
3100			.136	.136	1.53	.112	.894
3150			.127	.127	1.50	.110	.896
3200			.118	.118	1.47	.108	.898
3250			.110	.110	1.47	.108	.898
3300			.104	.104	1.46	.106	.899
3350			.097	.097	1.44	.105	.900

17

TABLE 3

FINAL STELLAR FLUXES

λ	Corr. Factor	Flux $(10^{-9}\text{erg cm}^{-2}\text{ s}^{-1}\text{ Å}^{-1})$		
		η UMa	α Lyr	ζ Oph
1750	.83	8.03	5.79	3.00
1850	.83	7.34	6.12	2.74
1950	.83	6.25	5.78	2.09
2050	.83	5.59	4.97	1.59
2150	.83	5.05	4.53	1.27
2250	.83	4.42	4.06	1.12
2350	.83	3.83	3.83	1.27
2450	.860	3.61	3.72	1.37
2550	.887	3.32	3.66	1.45
2650	.902	3.10	3.84	1.43
2750	.903	2.87	3.58	1.41
2850	.899	2.66	3.53	1.38
2950	.890	2.46	3.68	1.27
3050	.893	2.39	3.56	1.23
3150	.896	2.20	3.60	1.10
3250	.898	1.95	3.22	.99
3350	.900	1.75	3.24	.92

TABLE 4

TYPICAL ERRORS (%)

λ (Å)	NBS Error	Counting Error ± 1σ	Calibration Scatter	Air Extinction Error	Transfer Error	Total Error
1750	8	2	10	+17, -4	10	+24, -17
2150	8	1	10	+17, -4	10	+24, -17
2450	5	1	3	+17, -4	-	+18, -7
3050	3	2	3	+10, -7	-	+11, -8
3350	3	9	3	+11, -7	-	+15, -12

FIGURE CAPTIONS

Fig. 1   Measured O_2 cross sections at one atmosphere represented by discrete symbols. The line is the adopted cross sections including a dashed extrapolation.

Fig. 2   Air absorption coefficients. The solid line with circles and triangles is the adopted absorption coefficients. The lines with large dashes, dots, and the light solid line are the Rayleigh scattering, Rayleigh plus O_2, and Rayleigh plus O_2 plus ozone absorption coefficients, respectively. The small dash line and the dashed line with triangles and crosses are the lower and upper limits to the adopted coefficients.

Fig. 3   The absolute flux of η UMa from various experiments.

Fig. 4   The ratios of absolute fluxes of four independent measurements to the final fluxes derived from the OAO-2 satellite.
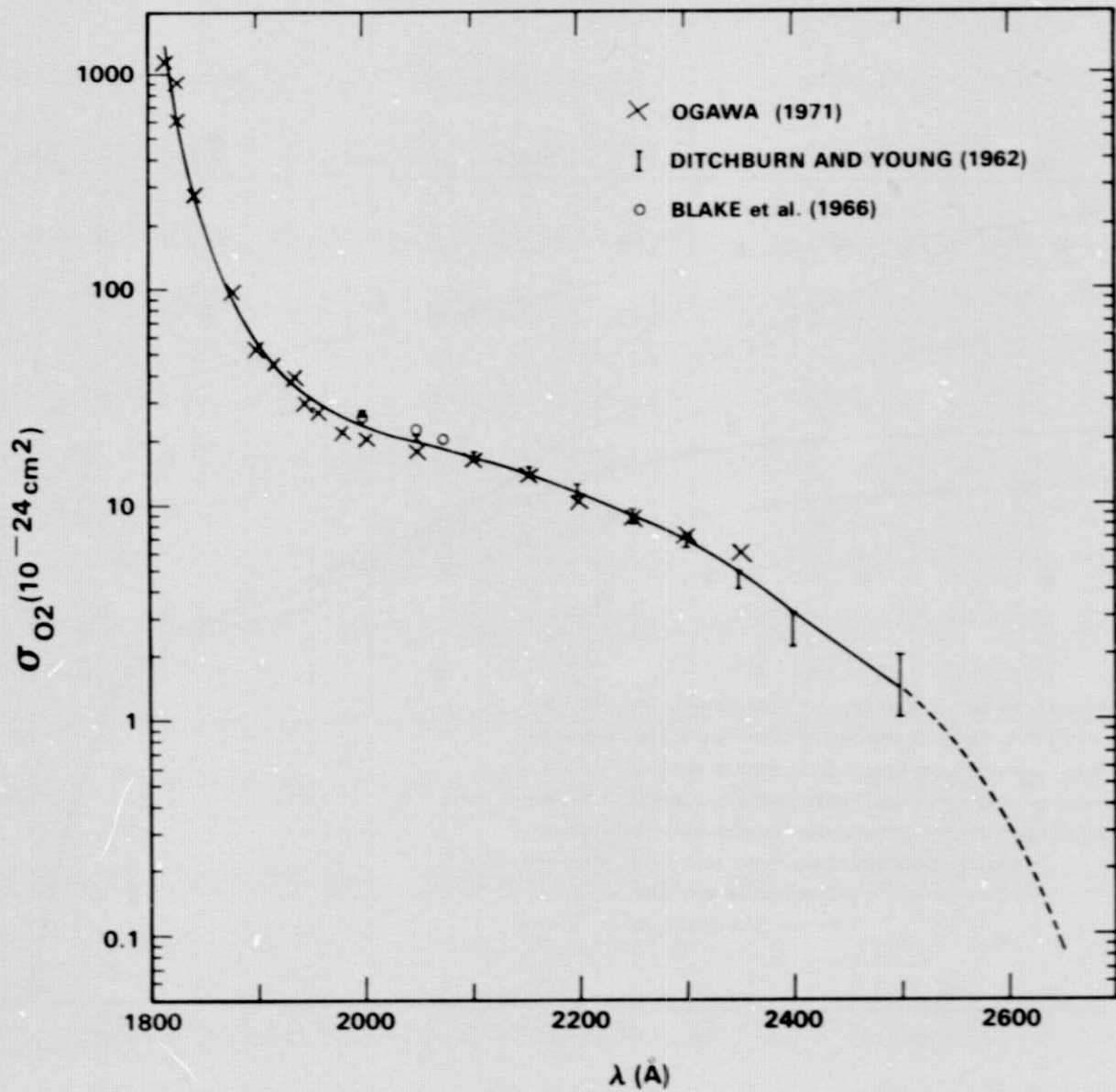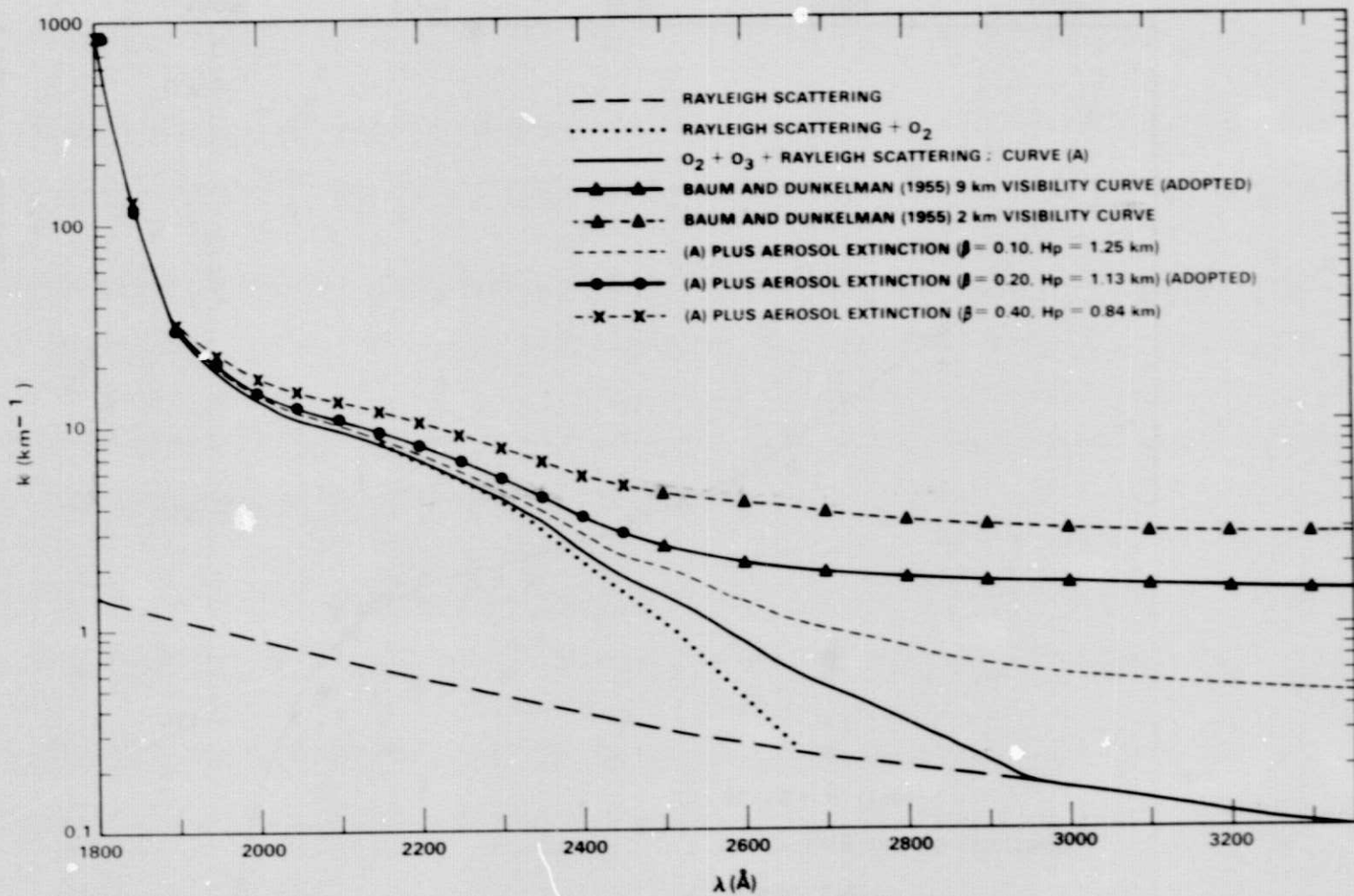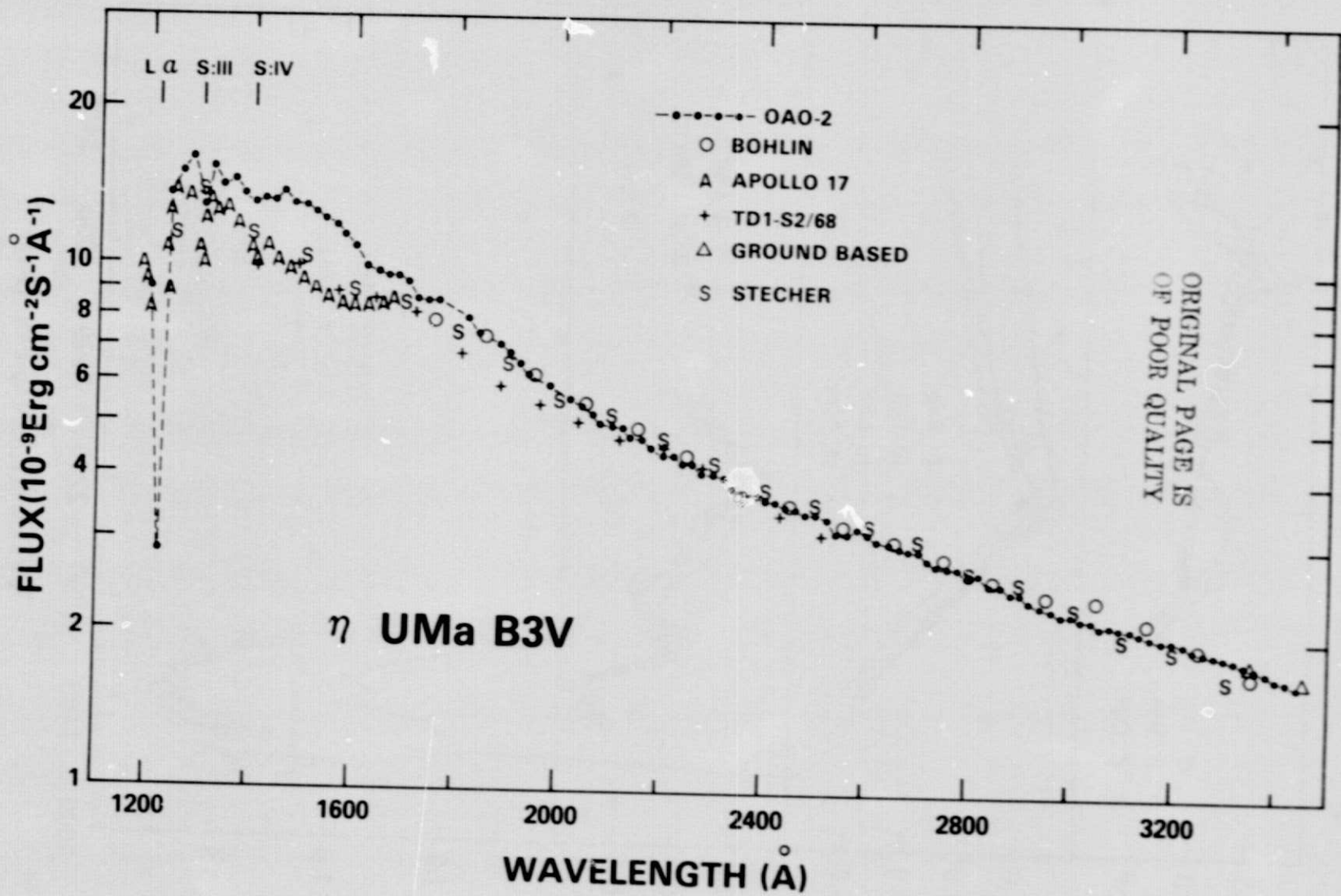
Fig. 1

Fig. 2

η UMa B3V

Fig. 3

Fig. 4
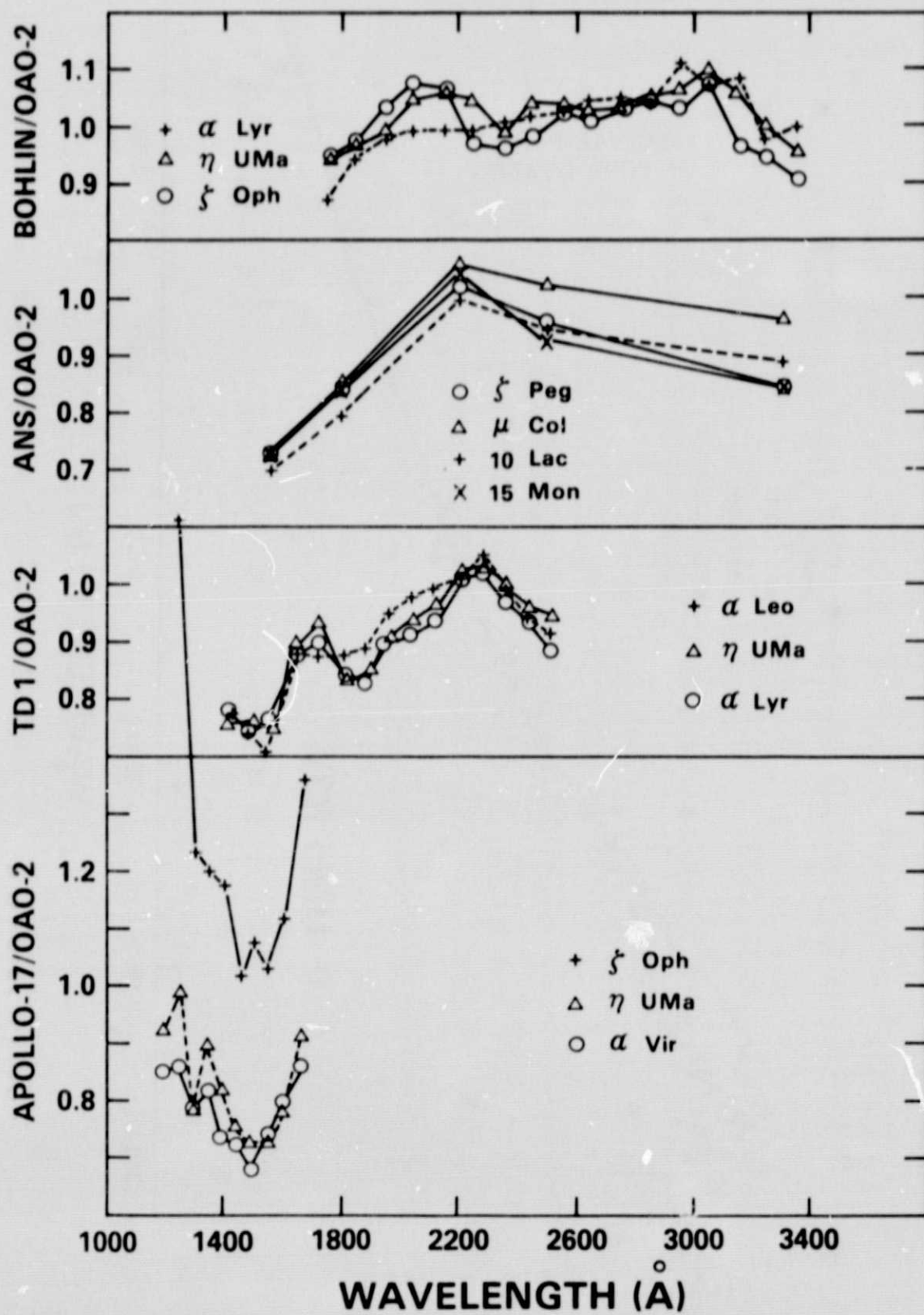
BIBLIOGRAPHIC DATA SHEET

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Absolute Calibration in the 1750-3350 Å Region		5. Report Date
		6. Performing Organization Code
7. Author(s) Ralph C. Bohlin & George J. Stronglis		8. Performing Organization Report No.
9. Performing Organization Name and Address Code 680, Lab. for Astronomy & Solar Physics Greenbelt, Md.		10. Work Unit No.
		11. Contract or Grant No.
		13. Type of Report and Period Covered
12. Sponsoring Agency Name and Address NASA/Goddard Space Flight Center Greenbelt, Maryland		
		14. Sponsoring Agency Code

15. Supplementary Notes

16. Abstract

The absolute flux measurements in the rocket ultraviolet made by Bohlin, Frimout, and Lillie (BFL) are revised using a more correct treatment of the air extinction that enters the air calibration of their instrument. The absorption by molecular oxygen and ozone, Raleigh scattering, and extinction by aerosols is tabulated for general use in ultraviolet calibrations performed in air. The revised absolute flux of η UMa and final fluxes for α Lyr and ζ Oph are presented in the 1750-3350 Å region. The absolute flux of the star η UMa (B3V) is compared to four other independent determinations in the 1200-3400 Å region and a maximum difference of 35% is found near 1500 Å between the OAO-2 and Apollo 17 fluxes. Longward of 1700 Å the typical scatter in the different determinations is only $\pm$ 5%. The rocket measurements of BFL, the ANS and TD-1 satellite data, and the Apollo 17 data are compared to the ultraviolet fluxes from the OAO-2, demonstrating a photometric reproducibility of about $\pm$ 3 percent. Therefore, all four sets of spectrophotometry can be reduced to a common absolute scale.

17. Key Words (Selected by Author(s)) absolute calibration - air extinction ultraviolet spectrophotometry - η UMa α Lyr, and ζ Oph	18. Distribution Statement - -

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages 25	22. Price*

*For sale by the National Technical Information Service, Springfield, Virginia 22151.

GSFC 25-44 (10/77)