

ABSOLUTE CALIBRATION OF
ULTRAVIOLET FILTER PHOTOMETRY

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The original spectrophotometric calibration of the Wisconsin telescopes on OAO-2 suffered from at least two important deficiencies: light sources available at that time radiated rather feebly in the far ultraviolet; and because of the requirements of spacecraft testing, the final laboratory calibration had to be performed 18 months before launch, although a limited field calibration in the 2000-4000 Å region was performed somewhat later.

When it became apparent that the OAO photometric system was stable and capable of considerable precision, we thought it important to attempt a new absolute ultraviolet calibration, both for OAO-2 and the then soon-to-be-launched OAO-B. Thus began the collaborative effort between the Wisconsin and Goddard groups (Evans 1972). Our intention was to fly small, simple telescopes in an Aerobee sounding rocket and measure the ultraviolet flux in several wavelength bands from a few bright, early-type stars which had also been observed by OAO. Such a rocket payload could undergo pre- and post-flight calibrations within a few weeks of the flight, as well as field calibrations a few days before and after the flight. Furthermore, a new source of ultraviolet radiation had become available to us, namely the synchrotron radiation from high energy electrons circulating in a storage ring. This facility, operated by the University of Wisconsin, consists of a synchrotron which accelerates electrons to about 50 mev, injects them into a storage ring in which, after further acceleration to about 240 mev, they can circulate for times of several hours at this energy. Thus the source is stable in time. In addition, the spectral energy distribution of the radiation approximates that of a B5 type star, i.e. the energy distribution of the stars we wish to calibrate; scattered light problems, which have plagued ultraviolet calibrations in the past, are thereby minimized. Finally, the absolute intensity of the beam can be

determined apart from any thermal sources so that the storage ring provides a calibration source completely independent of any previous absolute radiation standards. Such an absolute calibration is realized because it is possible to measure the synchrotron radiation from only one or two circulating electrons. Thus, by starting with about 50 electrons and measuring the step-wise decrease in intensity of the radiation each time an electron is ejected from the beam, one can determine the number of electrons producing a given signal. A simple extrapolation then gives the number of electrons (typically 300-500) used in the calibration, and thus the absolute intensity of that radiation.

The rocket payload consisted of seven telescopes, aligned to a common optical axis, each operating independently of the others with its own amplifier and power supply. Four of these were of a type we have flown before (see Bless et al. 1968), namely, two-inch suprasil quartz refractors with EMI 6256B photomultipliers as detectors, and three were four-inch aperture reflecting telescopes with EMR 541-type detectors at their focus. In each of the two-inch telescopes, transmission bands were shaped by two essentially identical three-layer aluminum-dielectric interference filters; the second filter significantly decreases the transmission in the wings. The 1550 Å band in one of the four-inch instruments was shaped by a single interference filter, whereas none were used in the remaining two reflectors, the long wavelength transmission edge being set by the photomultiplier response, the short wavelength edge by a CaF window. Peak photometer sensitivities were at about 2900 Å, 2400 Å, 2100 Å, 1900 Å (the two-inch instruments), 1550 Å and two at 1370 Å; bandwidths (FWHM) were about 250 Å. The field of view of each instrument was determined to be flat (to ~1%) over a 1° diameter circle; the total field was only slightly larger than this. An amplifier twenty times more sensitive than the primary amplifiers measured the background sky radiation, which was very small at all wavelengths.

The essential features of the calibration procedure can be divided into three parts. First, the shape of the bandpass of each photometer was determined by measuring the transmissions of the individual optical components and also by measuring the response of the photometer as a whole. For these relative measurements, a hydrogen lamp and ultraviolet monochromator provided the source radiation and sodium salicylate-coated photomultipliers served as the standard detectors. (Possible variations in the quantum efficiency of sodium salicylate are minimized here since constancy is assumed over only a few hundred angstroms for each instrument.) In calibrating the photometer as a whole, the objective was illuminated point-by-point by a nearly-collimated radiation bundle. Typically, six

points were measured at 25 Å intervals over the whole wavelength region of interest, and about 40 points were measured at two or three wavelengths.

Secondly, each photometer was placed in the essentially-collimated synchrotron radiation bundle maintained at a constant intensity level, and the output signal (using the flight electronics) determined from about 100 points on the objective. The sensitivity variations over the objective were small, about $\pm 10\%$.

Finally, two or three points on the objective were illuminated by synchrotron radiation at several different intensity levels covering the dynamic range of the photometers. The output signals were placed on an absolute basis by the electron counting technique described earlier.

This laboratory calibration was made several weeks before, and repeated a few weeks after, the flight. To monitor photometer response in the interval between these calibrations, a field calibration unit was constructed. The two-inch photometers were illuminated with uncollimated light having a band-pass defined by double interference filters essentially identical to those in the flight photometers. Reproducibility was assured by tight, positive mechanical coupling between the flight photometers and the calibration unit and by monitoring the source intensity. The calibration was carried out in air. The four-inch instruments were calibrated using parallel radiation from a four-inch collimator which could be sealed to the flight photometers and the whole system evacuated. The photometer responses were compared to those of two "standard" photometers which were constructed and calibrated in a manner similar to that of the flight instruments. Calibrations were made with this instrument a few weeks and a few days before the flight, one day after the flight, and finally a few weeks after the flight. The four-inch photometer responses varied by $\pm 9\%$ during this interval whereas that of the two-inch instruments varied by $\pm 5\%$.

The payload was flown on March 1, 1971 on an Aerobee 170 rocket and reached an altitude of 134 miles. All systems performed well and the three program stars, α Vir, η UMa and α Leo were observed as planned, viz., each object was observed at two to four mean altitudes for totals of from 40 to 80 seconds. This enabled an evaluation to be made of the extinction by the residual atmosphere of the earth, as well as that by rocket outgassing. These effects were not detectable except at the shortest wavelengths, where they required a correction of a few percent to the signals observed at or near peak altitude.

The results for η UMa are typical and are given in Figure 1 by the filled circles; open circles are the absolute measures of Schild et al. (1971). The observation at 1900 Å

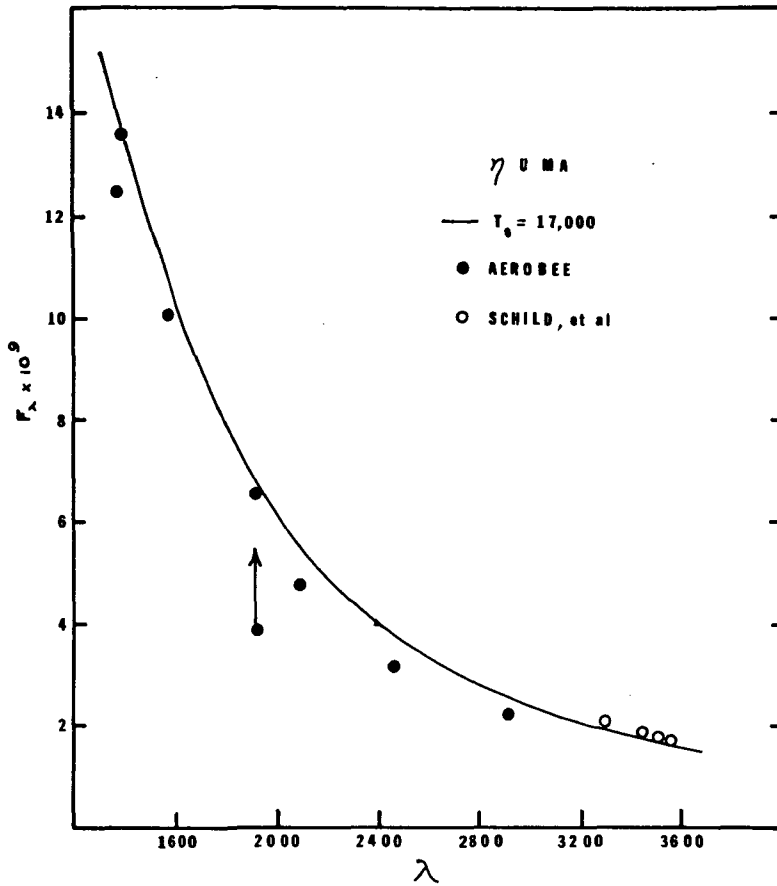


Figure 1.—Preliminary absolute ultraviolet fluxes from η UMa (filled circles), ground-based observations (open circles), compared with a hydrogen line blanketed model atmosphere with $T_e = 17000^\circ\text{K}$, fitted at the V magnitude.

falls below the general run of points for all three stars by the same factor; multiplying the observed flux in this band by 1.7 "corrects" this measurement. At this time we don't know what happened here; the pre- and post-flight laboratory and field calibrations are in good agreement for this photometer. In addition, the interpretations of the measurements at the three shortest wavelengths are somewhat ambiguous because these bandpasses include strong stellar absorption lines. The values plotted in Figure 1 may change by 10-15% when these ambiguities are resolved.

The solid line represents a hydrogen line blanketed model atmosphere with an effective temperature of 17000°K , calculated by Klinglesmith. This temperature is about the average of

that derived by Schild *et al.* (1971) and by Kodaira (1970) for this star. The model was fit only to the V magnitude of η UMa and represents the ultraviolet as well as the visual observations reasonably well. The points in the 2000-3000 Å region fall below the model atmosphere by about $0^m.15-0^m.20$. Line blanketing of this order was derived by Underhill (1972) for η UMa and probably explains most of the observed difference between our observations and the model in this spectral region. That line blanketing is affecting our measurements in the 2000-3000 Å region is also suggested by our results for α Vir and α Leo; in the former, the observations fall only slightly below an appropriate model, while in the latter, they fall farther below a model than do those of η UMa, just as Underhill's measurements of blanketing suggest they should.

These results indicate that model atmospheres, suitably corrected for blanketing, can be used to represent ultraviolet energy distributions, at least until the final observational results are available.

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