The Photometric Calibration of the *IUE* Final Archive

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I. Introduction

The *IUE* data, with more than 95000 high and low resolution spectra available, is not only a powerful tool for scientific research, but represents also an important reference for the flux calibration of other space experiments. The *IUE* Final Archive project (see Nichols-Bohlin et al. 1993), now in operational phase for low resolution spectra, aims to a complete reprocessing of all *IUE* data using an upgraded image processing system (NEWSIPS), new Intensity Transfer Functions for the three cameras, and new accurate values for the parameters affecting the effective exposure times and the sensitivity of the detectors (e.g. camera rise/fall times, aperture dimensions, time sensitivity degradation, temperature dependence of the camera sensitivity, and the like). In this way, both the homogeneity and the internal accuracy of the *IUE* archives should be substantially improved. Equally important for the photometric accuracy of the *IUE* Final Archive is the redefinition of the absolute flux scale, as discussed in the following.

II. The *IUE* Flux Scale

The initial *IUE* flux scale (Bohlin et al. 1980) is based on observations by other space experiments (basically *OAO-2* and *TD1*), each one affected by intrinsic systematic errors not well known at that time. In presence of discrepant measurements, and to force the convergence to a uniform flux scale (the η UMa flux scale as established by Bohlin et al. 1980), the original measurements were suitably weighted and flux correction factors were provided for the *OAO-2* and *TD1* experiments (Bohlin and Holm 1984). The η UMa flux scale is still being used by the *IUE* project as reference for the routine processing of *IUE* data (IUESIPS).

The *IUE* flux scale was not rediscussed until 1984–1985, when the project undertook the major task of obtaining a new set of ITF data for the three operational cameras SWP, LWP and LWR. These new data, together with an important set of observations of the usual *TD1* and *OAO-2* standards obtained in the same period, led to the recalibration of the three cameras, implemented in routine processing only for the LWP (Cassatella et al. 1992).

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The 1984-1985 recalibration phase, still based on the η UMa flux scale, was essential to take an independent look at the problem of the *IUE* flux calibration, and provided the basis for a critical revision of the assumptions made in the original calibration. One of the by-products of the new calibration was the discovery that the fluxes of some of the classical *IUE* standard stars were inconsistent with the internal *IUE* flux scale. Others were excluded because of suspected variability or because they contained unevenly exposed spectra. All these stars were then excluded in the definition of the set of standards to be used for the flux calibration of the *IUE* Final Archive.

The impetus to revise the *IUE* flux scale was given by increasing evidence for repeatable discrepancies between observations and models of objects of very different physical nature such as white dwarfs (Greenstein and Oke 1979), and BL Lac objects and sdO stars (Hackney et al. 1982). More recently, Finley et al. (1990) showed significant deviations (up to 15 percent) when comparing *IUE* fluxes and fluxes predicted by models of DA White Dwarfs. The fact that the above deviations were maximum in the regions where the disagreement between the original *OAO-2* measurements and the *TD1* fluxes was maximum was a clear indication for the presence of systematic errors in the η UMa flux scale.

Therefore, a major revision of the *IUE* flux calibration was considered a primary requirement at the moment of planning the activities inherent to the *IUE* Final Archive (Cassatella 1990). The fundamental basis of the recalibration plan was the intensive observational campaign carried out from VILSPA and GSFC in the period August 1990 to June 1991, intentionally limited in time to minimize the sensitivity variation of the detectors. The purpose was to obtain a statistically significant number of observations not only of the classical standard stars which the previous experience had shown to be the best, but also of a suitable set of hot objects including DA White Dwarfs and sdO stars. The list of WDs and sdOs was established in a meeting held at VILSPA in December 1990 attended by a small group of experts both on *IUE* calibration and in atmosphere modeling. As a necessary complement to this data set, several observations were made to test linearity, signal-to-noise ratio and repeatability, as well as to determine with the best possible accuracy all parameters affecting the effective exposure times and camera efficiency. The observational cost of this effort was about 40 shifts. Additional observing time was spent to obtain high resolution observations of some of the WDs and sdOs under an accepted proposal by the participants in the VILSPA meeting.

III. The Photometric Calibration of the *IUE* Final Archive

The most interesting proposal made at the 1990 *IUE* Calibration Meeting at Villafranca was to define a relative flux scale based on model atmosphere fluxes of a suitable sample of hot DA White Dwarf stars whose fluxes could be predicted with enough accuracy (Koester 1990). In other words, the models could be used to derive the shape (but not the flux zero point) of the sensitivity curves of the *IUE* cameras. The DA White Dwarf G191 B2B was considered as the most suitable candidate as primary standard. A pure Hydrogen model with T_{eff} = 58000 K and g = 7.5, here adopted, was considered accurate enough for G191 B2B, with the estimated error in the effective temperature (between 1000 and 2000 K) small enough to introduce a maximum uncertainty in relative fluxes of about 2 percent over the *IUE* spectral range (Koester 1990). An additional advantage of G191 B2B is that, because of its high effective temperature and the consequently narrow Lyman profile, also the region near the short wavelength end of the SWP camera can be calibrated accurately. Although some authors have reported the presence of metals in the atmosphere of G191 B2B (see for instance Bruhweiler and Kondo 1981, Vennes 1992 or Barstow et al. 1993), their abundance is extremely low, so that the difference between pure Hydrogen models and models including metals is nearly negligible in the spectral range of interest (Finley, this volume).

The above-mentioned model of G191 B2B, together with several low resolution spectra of G191 B2B obtained in 1990–1991 were used to derive the relative inverse sensitivity curves of the SWP and LWP cameras in that period. The relative inverse sensitivity curves were then used to find the relative fluxes of the remaining standards, including other WDs, some sdO stars and the best classical standards, whose spectra were also obtained in 1990–1991.

The next step was to find a coherent way of defining the zero point of the absolute scale. A direct use of the model atmosphere absolute fluxes was excluded *a priori* because of the too large errors implied by the not yet adequate knowledge of the stellar parameters. A second possibility, also excluded, was to normalize the model fluxes to existing photometric or spectrophotometric observations in the optical range. The extrapolation of the fluxes over such a wide spectral range, from the optical to the UV, had, in fact, the major drawback of amplifying in the UV the uncertainty not only in the model, but also in the optical data. The choice finally made was to set the zero point by comparing, for the same star, the relative fluxes derived as described above, with the UV fluxes as measured by other space experiments. Which experiment to select as reference and in which wavelength the zero point should be set is of course the most critical problem. Finally, it was considered that the procedure ensuring the best accuracy was to find the flux zero point by scaling the relative fluxes of the brightest *IUE* classical standard stars taking as reference the *OAO-2* fluxes in the spectral band 2100–2300Å. Indeed, it is in this band where the previous space experiments agree best (within 2 percent for *OAO-2* and *TD1*, see Bohlin et al. 1980).

The absolute fluxes of the *IUE* standards observed in 1990–1991 were then used as input fluxes to derive the inverse sensitivity curves for 1985, chosen as zero epoch for the flux calibration of the *IUE* Final Archive output data. The corrections for time-dependent sensitivity degradation of the *IUE* cameras, implemented in the Final Archive, are referred to this epoch. A full description of the method as applied to the SWP and LWP cameras has been given in Gonzalez-Riestra et al. (1992, 1993).

The differences between the new and the old flux scales can be appreciated in Figure 1 where we show the ratio of the new flux and the old one (as given by Bohlin and Holm 1984) for two of the *IUE* standard stars (HD 60753 and λ Lep). The discontinuities in this ratio clearly indicate the errors in the previous flux scale. Especially in the short wavelength range, there are large fluctuations of up to 15–20 percent over intervals less than 100Å wide. In the long wavelength range the ratio is more constant except for a substantial decrease longward 3100Å where the old fluxes were overestimated by 20 percent. Figure 2 shows the average ratios (New Flux/Old

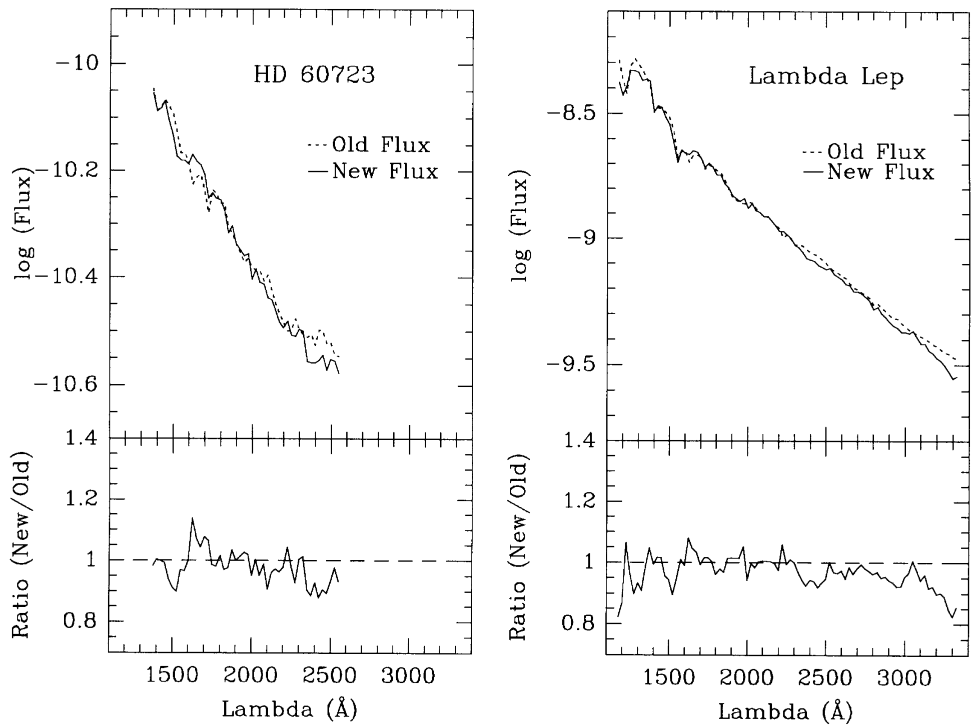

Figure 1: Comparison of old and new fluxes for the standard stars HD 60753 and Lep. The old fluxes have been taken from Bohlin and Holm (1984) and the new ones have been derived with the present calibration.

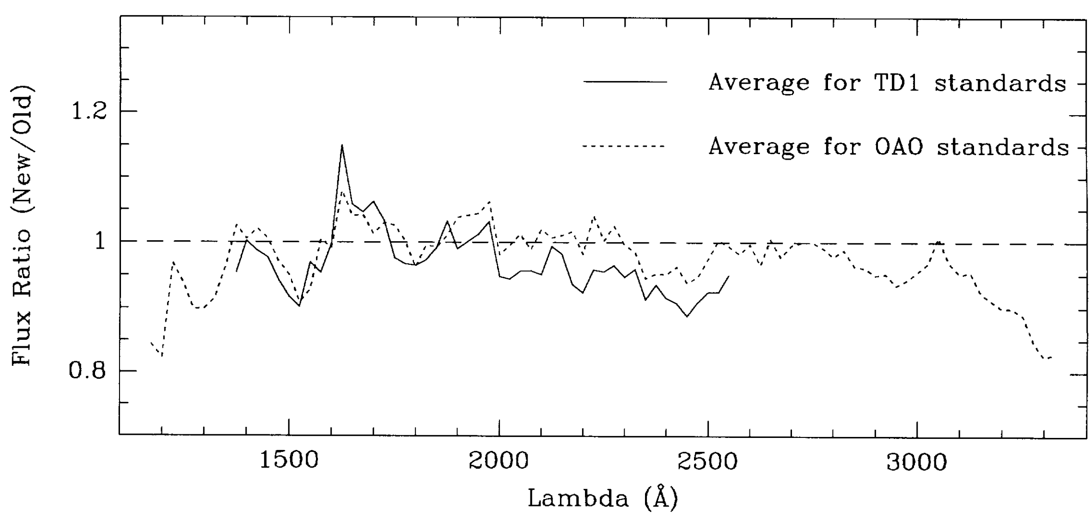

Figure 2: Average ratios New flux / Old flux for *TD1* and *OAO-2* standards.

Flux) for several *TD1* and *OAO-2* standard stars. The factors to be used to put the original *TD1* and *OAO-2* fluxes in the new *IUE* Flux scale are shown in Figure 3, where they are compared to the correction factors given by Bohlin and Holm (1984).

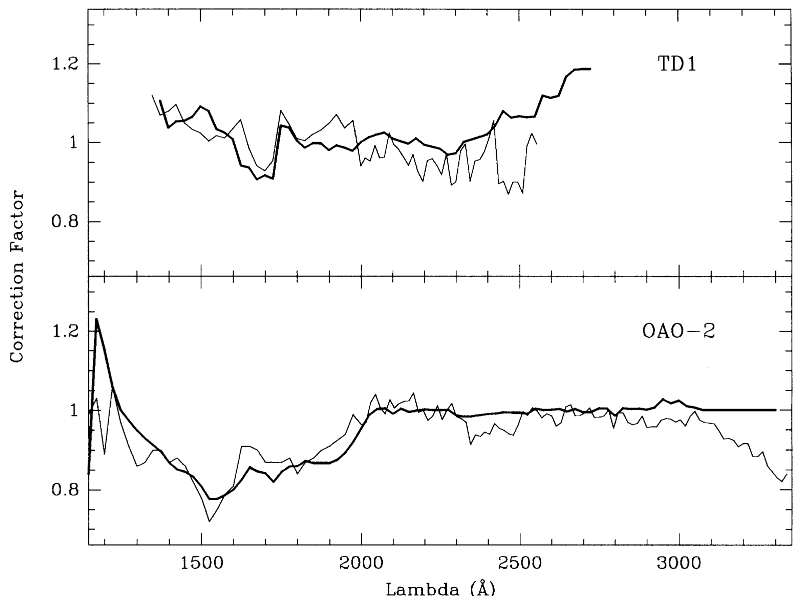

Figure 3: New correction factors to the original *TD1* and *OAO-2* fluxes (thin lines). For comparison, the correction factors given by Bohlin and Holm (1984) are shown as thick lines.

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