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WFPC2 Calibration for Emission Line Images

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Abstract. Formulae for the flux calibration of WFPC2 emission lines are presented. The photometric information given in the header is not adequate, and does not consider the contamination due to neighbouring emission lines in the filter passband or by the continuum. The formulae were originally calibrated using ground-based images of the Orion Nebula. The photometric accuracy of the flux calibration process is assessed by comparing WFPC2 fluxes with ground-based absolute fluxes and aperture photometry of four bright planetary nebulae. A 5 % absolute accuracy for the Hα emission line is achievable using this method.

1. Introduction

The flux calibration of HST images is a well studied problem in reference to wide band filters. The accuracy of these calibrations is claimed to be ∼5% (Holtzmann et al. 1995). The header of the HST images provides the values of the parameter PHOTFLAM for each of the individual images, which allows, in principle, a direct conversion from data numbers (DNs) into physical flux in units of erg cm^{-2} s^{-1}. As PHOTFLAM actually represents the *mean* flux density (i.e., the flux density of a source with a spectrum which is flat in f_λ across the bandpass of the filter), this calibration method is not applicable to sources whose spectra differ significantly from flat (strong slope or emission lines for example).

The WFPC2 narrow band filters are mostly used for the observation of emission line objects and their flux calibration should therefore not be made using the PHOTFLAM parameter. A formula is proposed by Holtzmann et al. (1995) to convert from observed count rates into physical fluxes. The knowledge of the system throughput at the wavelength of the emission line is required; these throughputs can be read from tables available via the WFPC2 homepage (in `/ftp/cdbs/cdbs6/synphot_tables/`). A major source of uncertainty is that these tables rely on the pre-launch filter transmission curves and on observation of continuum sources, as no known flux calibration with emission line sources has been carried out to date. This situation should change when the results of the proposal 6943, *Throughput verification for narrow band filters*, of the Cycle 6 calibration plan become available.

A last source of uncertainty in the calibration of narrow band filters is the possible contamination by neighbouring emission line(s). This problem has been recently considered in the flux calibration of WFPC2 images of BD +30^{o}3639 (Harrington et al. 1997). The flux calibration of the F656N and F658N filters was corrected by 14% and 4% to account for the contamination by the [NII] (6548Å and 6584Å) and Hα 6563Å lines respectively. The quoted percentages were measured from the pre-launch filter transmission curves, and

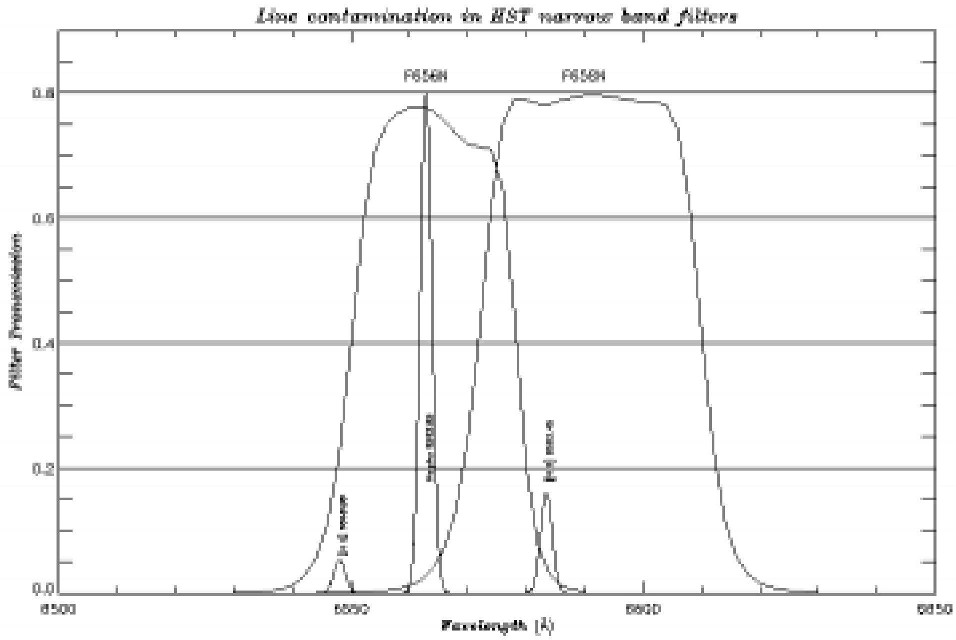

Figure 1. WFPC2 filter F656N and F658N bandpasses are shown with Hα and [NII] emission lines. F656N is contaminated by the [NII] 6548Å and 6584Å lines, at which its transmission is $\sim$ 29% and $\sim$ 4% respectively. The F658N filter is contaminated by the Hα 6563Å line, transmission $\sim$ 4%.

since the contaminating lines lie on the steep shoulder of the filter passband (see Figure 1), additional inaccuracy can be expected from even a slight change in the transmission curves.

In Section 2, we present analytical formulae for the F502N, F656N and F658N narrow band filters that directly solve for the emission line nature of the object and for the possible contamination. The accuracy of the calibration is tested by comparing the total flux of four planetary nebulae (PNe) derived from HST images with ground-based measurements (Section 3) and brief conclusions are given in Section 4.

2. Calibration Formulae

An accurate absolute calibration of the HST Hα (F656N), [OIII] (F502N) and [NII] (F658N) narrow band filters was performed by comparing ground-based Orion Nebula images with the corresponding HST frames. The method described here is the application to WFPC2 narrow band filters of the method employed by Hu for the calibration of the WFPC narrow band filters (Hu 1997a, 1997b). The equations presented here were obtained for the WFPC2 filters by Wong (unpublished) and kindly provided to us by C. R. O'Dell. Several smooth regions of the ground-based Orion [OIII], Hα and [NII] images, obtained by R. J. Dufour, were used to calibrate the formulae relating the surface brightness of the emission lines to the measured counts in DN. The other quantities needed were obtained from the HST WFPC2 Instrument Handbook (Biretta et al. 1996).

Practical formulae give the surface brightness of lines in photons cm^{-2}s^{-1}ster^{-1} as a function of data number and exposure time. These formulae directly take into account the contamination of the Hα(F656N) filter by the [NII] 6548Å and 6584Å lines (and the contamination of the [NII](F658N) filter by the Hα 6563Å line) and allow the correction of this effect on a pixel-to-pixel basis. This is particularly important as the [NII] emission arises from low ionization regions that can be spatially different from the Hα emission (for example, low ionization knots in PNe).

The first three formulae also include a correction term for the continuum if F547M observations are available. This correction is more important for HII regions than for PNe. In HII regions, the scattered light continuum can be much stronger than the atomic continuum which dominates in PNe.

We applied a further multiplicative factor to the given equations to obtain the fluxes in units of erg cm^{-2}s^{-1}. Lastly, care must be taken of the analog to digital gain which was used for the HST observations. The final equations used for the Hα(F656N), [NII](F658N), [OIII](F502N) and Hβ(F487N) flux conversion are listed below. The formula for the F487N flux was obtained by directly comparing the total line flux in counts in BD+30°3639 (the continuum contribution inside the F487N filter was estimated and subtracted) to the total Hβ flux quoted in the ESO Strasbourg catalogue of PNe (Acker et al. 1992).

$$F_{502}(ergs^{-1}cm^{-2}) = \frac{N_{502}\times g}{t_{502}\times 8.71\ 10^{13}} \times \frac{1}{1+\frac{0.03\times t_{502}\times N_{547}}{t_{547}\times N_{502}}} \quad (1)$$

$$F_{656}(ergs^{-1}cm^{-2}) = \frac{N_{656}\times g}{t_{656}\times 2.45\ 10^{14}} \times \frac{1}{1+\frac{0.15\times t_{656}\times N_{658}}{t_{658}\times N_{656}}+\frac{0.05\times t_{656}\times N_{547}}{t_{547}\times N_{656}}} \quad (2)$$

$$F_{658}(ergs^{-1}cm^{-2}) = \frac{N_{658}\times g}{t_{658}\times 2.64\ 10^{14}} \times \frac{1}{1+\frac{0.04\times t_{658}\times N_{656}}{t_{656}\times N_{658}}+\frac{0.07\times t_{658}\times N_{547}}{t_{547}\times N_{658}}} \quad (3)$$

$$F_{487}(ergs^{-1}cm^{-2}) = \frac{N_{487}\times g}{t_{487}\times 7.59\ 10^{13}} \quad (4)$$

Where:

F_{filter}	Flux calibrated image in units of erg s^{-1} cm^{-2}
N_{filter}	Data Number (DN) counts in HST images
t_{filter}	HST image exposure time in second
g=1	if the analog to digital conversion factor of the observation is 7 (header keyword ATODGAIN = 7)
g=2	if the analog to digital conversion factor of the observation is 14 (header keyword ATODGAIN = 15)

3. Comparison with Other Observations

3.1. HST Observations

In order to assess the validity and accuracy of the flux calibration formulae presented above, we performed a comparison of the total fluxes obtained from ground-based observations and from HST observations. From the HST archive, we obtained Hα(F656N), [NII](F658N) and [OIII](F502N) HST images of four bright planetary nebulae, namely NGC 3242, NGC 6826, NGC 7009 and NGC 7662 (PI: B. Balick, proposal number 6117). The data were pipeline calibrated with the most up-to-date calibration files (on-the-fly calibration). The calibration pipeline includes the bias subtraction, dark subtraction and flat fielding of the data. Images taken in the same filter were combined into one equivalent exposure; the data reduction further included a linear interpolation over bad pixels and the cosmic ray cleaning process. The mosaic image of NGC 7009 was built by combining the PC and WF images. The other PNe were all exposed within the field of the PC camera. We then applied the flux calibration formulae (1)–(4) to obtain images in units of erg cm^{-2} s^{-1}.

The last contamination to take into account and subtract is the nebular continuum emission in the filter passband. Using the DIPSO package (Howarth et al. 1995), the nebular continuum spectrum was calculated for each nebula, based on the observed total Hβ flux, the extinction and the nebular conditions. Using the CALCPHOT task of the IRAF SYNPHOT package, the continuum contribution in counts per second was estimated inside each filter passband. As an example, the continuum contribution in the Hα(F656N) filter for NGC 3242 was found to represent 1.5% of the line flux, and the flux in this image was reduced correspondingly. The same calculation was made for the other filters and the continuum removed as a fraction of the Hα image.

3.2. Ground-based Observations

We adopted total Hβ fluxes for the above mentioned PNe from Acker et al. (1992). We then compiled the logarithmic redenning parameter, c, from the literature. For NGC 3242 a reddening value of $c = 0.11$ was adopted from radio measurements. For NGC 7662, $c = 0.23$ was adopted from the study of Harrington et al. (1982). Finally, the value of the redenning parameter for NGC 6826 and NGC 7009 was 0.16 and 0.12 respectively, adopted from the work of Barker (1983, 1988). Using the theoretical case B dereddened line ratio value of 2.83 between Hα and Hβ (representative of the mean nebular conditions $N_e = 4000\,\mathrm{cm}^{-3}$, $T_e = 11000\,\mathrm{K}$ of these PNe), we derived the total Hα observed flux for each of the PNe. The error on the observed Hβ fluxes is 0.02 dex, the error on the theoretical line ratio is no more than 1%, and an ± 0.05 error on the redenning parameter c can contribute up to 0.02 dex. We then estimate the error on the observed Hα flux to be 0.04 dex in total.

We also obtained the global [OIII] fluxes for the nebulae from the literature (see footnotes to Table 1). These [OIII] observations were always obtained together with Hβ ones, and the [OIII] flux was rescaled if ever these Hβ fluxes were different from the one in the Acker et al. (1992) catalogue. The error on the [OIII] flux hence encompasses the 0.02 dex error on the observed Hβ flux of the Acker catalogue and the one of the observations, usually 0.03 dex. We hence adopt a total [OIII] error of 0.04 dex.

Table 1 summarizes the comparison between the [OIII] and Hα ground-based measured fluxes and the HST fluxes obtained from our calibration. (There were no HST Hβ images taken of these PNe.) The total Hα fluxes measured from HST compare very well with the ground-based estimate. The mean difference between Hα fluxes for the 4 objects is only of 0.02 dex. Comparing this value to the error on the ground-based Hα measurements of 0.04 dex, we conclude that the flux calibration formula for the Hα images is probably correct to 0.02 dex (or 5%). There is also no indication of a systematic error on the measurement.

Imaging spectrophotometry was recently performed on NGC 7009 and NGC 7662 (Lame & Pogge 1996). The flux calibration method relied on the comparison with flux calibrated long slit spectra at well-determined positions. However, the quoted total Hβ line fluxes within a 40$''$ diameter circular aperture are underestimated by 0.16 and 0.14 dex for NGC 7009 and NGC 7662 respectively, compared to the values from the Acker et al. (1992) catalogue. Nevertheless, rescaling their [OIII] total flux accordingly, we obtained a total logarithmic [OIII] flux of -8.71 for NGC 7009 and -8.89 for NGC 7662. For NGC 7009, a previous measurement of Webster (1983) gave a total logarithmic [OIII] flux of -8.73. Using the rescaled measurements of Lame & Pogge (1996) reduces the discrepancy with our HST determination to 0.04 dex for NGC 7009, while leaving it unchanged for NGC 7662. This also illustrates the difficulty in obtaining a good calibration from the ground for extended emission line objects.

The mean difference between the ground based and the HST [OIII] fluxes however reaches 0.04 dex. The errors appear to be correlated with the error on the Hα fluxes, and for 3 out of 4 objects, the HST [OIII] fluxes are $\sim$0.04 dex higher than the ground-based ones. The flux calibration formula for the [OIII] images is probably correct to 0.04 dex (or 10%).

Table 1. Comparison of Hα and [OIII] absolute logarithmic fluxes

Object	Hβ^a	c	Hα	HST Hα	[OIII]	HST [OIII]
NGC 3242	-9.79	0.11	-9.30	-9.33	-8.63[b]	-8.66
NGC 6826	-9.98	0.16	-9.48	-9.46	-9.12[c]	-9.05
NGC 7009	-9.78	0.12	-9.29	-9.26	-8.71[d]	-8.67
NGC 7662	-9.99	0.23	-9.46	-9.46	-8.89[c,d]	-8.85

[a] log Hβ flux in erg cm^{-2} s^{-1} from Acker et al. (1992)

[b] Collins et al. (1961)

[c] Capriotti & Daub (1960)

[d] Lame & Pogge (1996)

4. Conclusions

We have presented formulae for the flux calibration of WFPC2 Hα (F656N), [OIII] (F502N) and [NII] (F658N) narrow band filters. A 5% absolute accuracy for the Hα emission line (10% for the [OIII] line) is achievable using this method. The accuracy for the [NII] emission line cannot be assessed from available global flux measurements. Further progress towards an accurate flux calibration for other narrow band filters is expected from the results of the proposal 6943 (Throughput verification for narrow band filters) of the Cycle 6 calibration plan.

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