Flux calibration of low resolution spectra

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In applying the method of David Boyd [1] to flux calibration of low resolution spectra, I found it instructive to look at the whole question of what 'luminous flux' is all about...

Flux is an *energy* based concept, but modern sensors like CCDs register photon counts and not energy per se. Therefore, what we have in the first instance in our spectra is a measure of the *photon count* at each wavelength (albeit transformed through factors like quantum efficiency, gain, normalisation etc.). This distinction is observed in the literature - see for example [2, 3] - and is well described in several online lecture notes [4, 5, 6] .

To see what is involved here, let $f_s(\lambda)$ be the absolute *flux density* from a source s. Flux density is the energy falling on a unit area, per unit time, at a given wavelength; in one popular system of units, it is expressed in erg/cm^2/sec/Å. To transfer this to a photon count, we note that the energy $E(\lambda)$ of a photon of wavelength λ (or equivalently, frequency ν) is given by

$$E(\lambda) = h\nu = \frac{hc}{\lambda} \tag{1}$$

Then, the *photon flux density* $\phi(\lambda)$ is related to the flux density by dividing the latter by the photon energy. That is

$$\phi(\lambda) = \frac{f(\lambda)}{E(\lambda)} = \frac{\lambda f(\lambda)}{hc} \tag{2}$$

Therefore, ignoring any scaling which will be absorbed in normalisation,

$$\begin{aligned} \phi(\lambda) &= \lambda f(\lambda) \\ f(\lambda) &= \frac{\phi(\lambda)}{\lambda} \end{aligned} \tag{3}$$

Thus, in order to transform from counts to flux, we should divide our raw spectrum amplitude at each wavelength, $\phi(\lambda)$, by the wavelength. This begs the question - 'why don't we do this?'. In fact, we do, implicitly, if we do instrument correction against a standard library like MILES, because these are given in terms of relative flux.

To see this, let $f_M(\lambda)$ be the relative flux density of the MILES reference given in the database, and $\phi_m(\lambda)$ the instrumental spectrum (from our observation) for this star, given in counts. Then the *instrument response*, $IR(\lambda)$ we compute is given by [1]

$$IR(\lambda) = \frac{\phi_m(\lambda)}{f_M(\lambda)} \tag{4}$$

This looks, at first glance, like a rather odd operation because it involves different classes of variable (photon counts and fluxes). However, it can be reconciled because we are actually doing two operations in one step: (i) converting to flux and (ii) finding a genuine 'instrument response'. Thus, from (4) and (3)

$$\begin{aligned} IR(\lambda) &= \frac{\lambda f_m(\lambda)}{f_M(\lambda} \\ &= \lambda R_f(\lambda) \end{aligned} \tag{5}$$

where R_f is a 'true' instrument response – relating two flux spectra – which we might expect to be that truly given by the transmission properties of the atmosphere, instrument etc. In contrast, IR includes a factor λ which has to do with converting from counts (in the 'raw' spectrum) to flux. Thus, we use IR, applied to the spectrum $\phi_s(\lambda)$ from some target s, to compute a corrected spectrum $f_s^*(\lambda)$ by computing $\phi_s(\lambda)/IR(\lambda)$. That is

$$\begin{aligned} f_s^*(\lambda) &\equiv \frac{\phi_s(\lambda)}{IR(\lambda)} \\ &= \frac{1}{R_f(\lambda)} \frac{\phi_s(\lambda)}{\lambda} \\ &= \frac{f_s(\lambda)}{R_f} \end{aligned} \tag{6}$$

where $f_s(\lambda)$ is is a relative flux density. So, f_s^* is indeed, also a flux density.

We could, of course proceed explicitly in two steps by first finding f_s (recall $f_s(\lambda) = \phi_s(\lambda)/\lambda$) and then finding R_f. While this is not necessary, it is instructive to compare f_s and ϕ_s in an exemplar – see Fig 1. This shows the uncorrected spectrum of a MILES star (HD174959) in red, corresponding to ϕ_s. The black dashed line shows $f_s = \phi_s/\lambda$, and the thinner, solid black line, the final corrected spectrum f_s/R_f.

[1] There is a finesse with smoothing, but we assume that IR is the underlying smooth function we are trying to capture

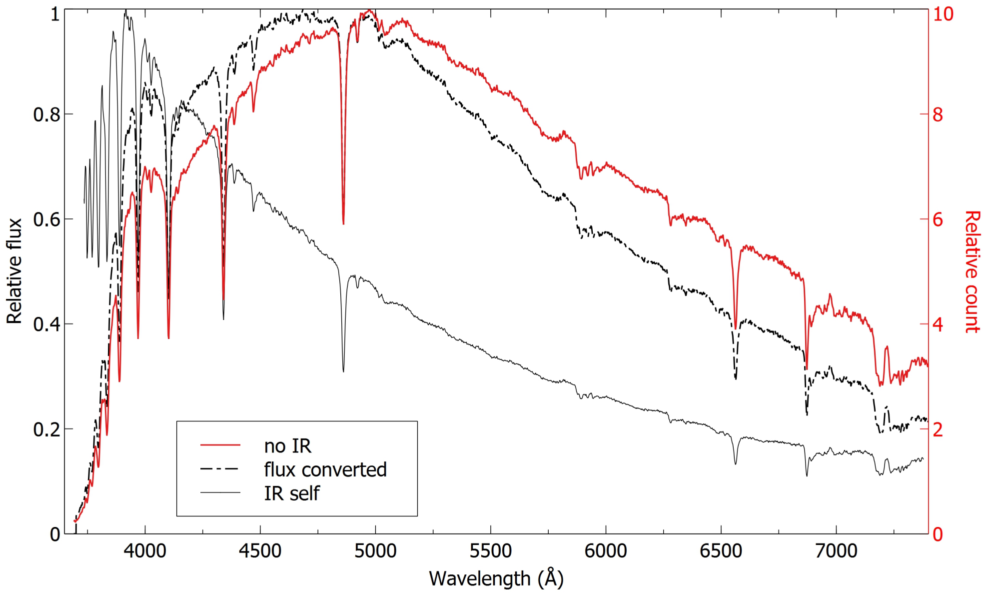

Figure 1: Breaking out the count-to-flux conversion in the the usual calculation of an ALPY 'instrument response'

References

[1] David Boyd. Observing with a LISA spectrograph. `http://www.shelyak-instruments.com/Web/slides/20151010fBAAVSSNLO-ObservingwithaLISAspectrograph(DavidBoyd).pdf`.

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[3] Peter J. Brown, Alice Breeveld, Peter W. A. Roming, and Michael Siegel. Interpreting Flux from Broadband Photometry. *The Astronomical Journal*, 152(4):102, October 2016.

[4] S.P. Littlefair. PHY104 - Introduction to Astrophysics, 2013. `http://slittlefair.staff.shef.ac.uk/teaching/phy217/resources/completeNotes.pdf`.

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