Cross-Calibration Using Twilight

v1.0
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1 Introduction

Here I examine the question of whether twilight observations are suitable for establishing the cross-calibration between the SNIFS imager and spectrograph channels. The basic concept is that the twilight sky is very nearly uniform over the modest field of view of SNIFS, so the ratio of any monochromatic flux in the two channels provides the cross-calibration.

There are potential problems which need to be examined. The most obvious is that observations with the imager will be of significantly lower spectral resolution than with the spectral channels. Thus, monochromatic flux ratios cannot be obtained, and the impact of this must be examined. In addition to this, the spectral shape of the twilight sky changes depending on the sun-sky-telescope geometry. This can effect the resulting fluxes measured in the imager relative to the spectrograph because the imager filter(s) integrate over the spectrum.

Let us denote the spectrum of the twilight sky at time t as $S_s(\lambda, t)$, the transmission of the spectrograph as $T^{(s)}(\lambda, t)$, and that of the imager as $T^{(p)}(\lambda, \lambda_0, t)$. Here λ_0 denotes the central wavelength of either a standard filter, or the position-dependent central wavelength of a linear ramp filter.

Observation of the twilight sky with the imager at time t_1 yields:

$$O_I(\lambda_0, t_1) = \int_0^\infty T^{(p)}(\lambda, \lambda_0, t_1) S_s(\lambda, t_1) d\lambda$$

while we assume that the flux in the spectral channel is nearly monochromatic, yielding:

$$O_S(\lambda_0, t_1) = T^{(s)}(\lambda_0, t_1) S_s(\lambda_0, t_1)$$

Likewise, observations at t_2 yield $O_I(\lambda_0, t_2)$ and $O_S(\lambda_0, t_2)$.

Assume the simplest case that the time between t_1 and t_2 is short enough that the transmissions have not changed. Then $T^{(p)}(\lambda, \lambda_0, t_1) = T^{(p)}(\lambda, \lambda_0, t_2)$

and $T^{(s)}(\lambda, t_1) = T^{(s)}(\lambda, t_2)$. Further, assume that the imager transmission can be described as a box function of unit peak, centered on λ_0 with width $\Delta\lambda$, and that the spectrograph transmission is a delta function at λ_0. In this case, a minimum requirement for the twilight sky to be a suitable cross-calibration source is that different observations of twilight sky give consistent values of $O_I(\lambda_0, t_1)/O_S(\lambda_0, t_1)$ and $O_I(\lambda_0, t_2)/O_S(\lambda_0, t_2)$.

Therefore, given two spectra of the twilight sky, the ratio

$$R(\lambda_0) \equiv \frac{O_I(\lambda_0, t_1)}{O_S(\lambda_0, t_1)} \bigg/ \frac{O_I(\lambda_0, t_2)}{O_S(\lambda_0, t_2)} = \frac{\int\limits_{\lambda_0-\Delta\lambda/2}^{\lambda_0+\Delta\lambda/2} S_s(\lambda, t_1) d\lambda}{S_s(\lambda_0, t_1))} \bigg/ \frac{\int\limits_{\lambda_0-\Delta\lambda/2}^{\lambda_0+\Delta\lambda/2} S_s(\lambda, t_1) d\lambda}{S_s(\lambda_0, t_1))}$$

is a diagnostic of how well twilight calibration is capable of performing cross-calibration at wavelength λ_0. Next we examine the behavior of $R(\lambda_0)$ for two example twilight sky spectra.

2 Example Cross-Calibration using Twilight Spectra

I use two flux-calibrated twilight spectra obtained at zenith with the RC spectrograph on the CTIO 4-m telescope in May 2000. The exposure times for the evening twilight was 10 seconds, while that for the morning twilight was 120 seconds. The two spectra are shown in Fig 1, and their ratio is shown in Fig 2. The most obvious differences are at longer wavelengths, where the amount of atmospheric absorption due to water and O_2 vary between the two exposures. This can occur due to changing atmospheric conditions, causing more absorption directly or through increased multiple scattering in optically thick lines.

I wrote a simple routine to calculate the value of $R(\lambda_0)$ with values of $\Delta\lambda$ ranging from 100Å to 1000Å using these two spectra. I than ran a 100Å-wide median filter over the results to highlight regions in which $R(\lambda_0)$ is well-behaved. The results are shown in Fig. 3.

Our minimum requirement is that the cross-calibration be better than 1%. It need not be this accurate at all wavelengths, but it must be good enough so that good cross-calibration can be obtained for filters being used to determine the extinction from imaging data. In the case of a linear ramp filter, this statement can be turned around to state that the extinction can

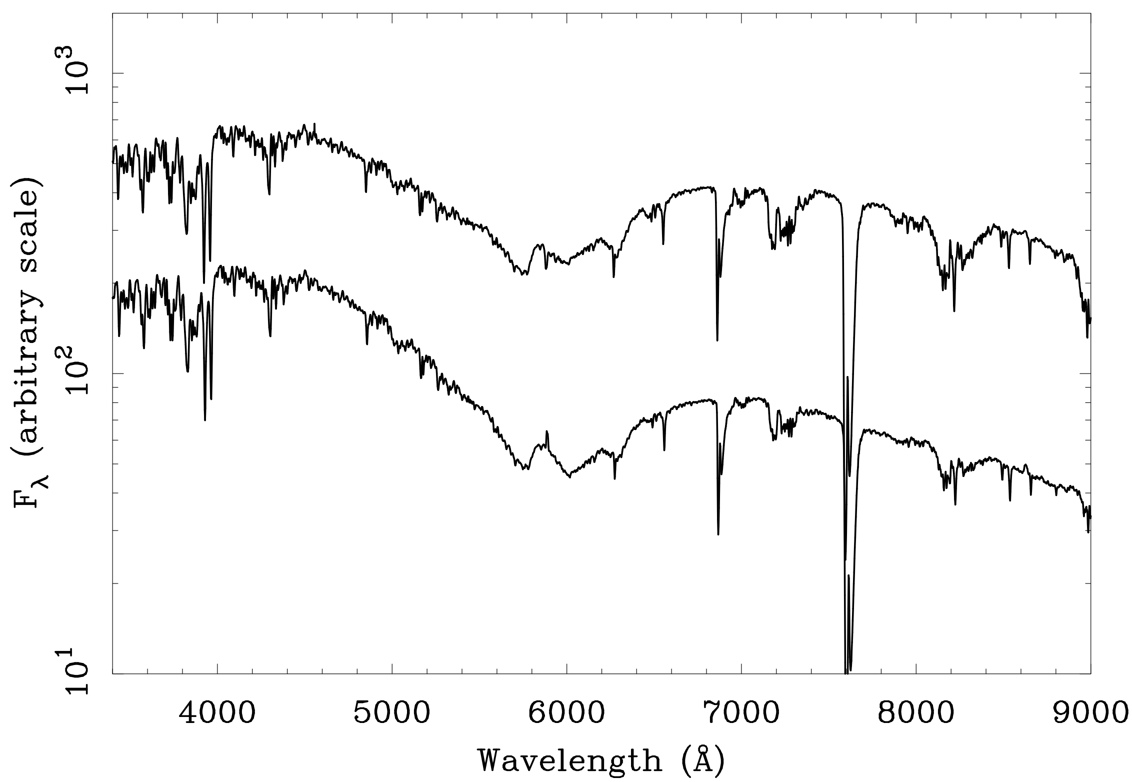

Figure 1: Two example twilight spectra obtained at CTIO. Note that beyond about 7000Å there is the possibility of contamination from 2nd-order light. However, a careful search for 2nd-order versions of strong solar absorption lines showed no evidence for 2nd-order light out to 8600Å. Lack of detectable 2nd-order light for $\lambda < 8000$Å is consistent with observations of very blue spectrophotometric standard stars. Both spectra were taken at an airmass of 1.

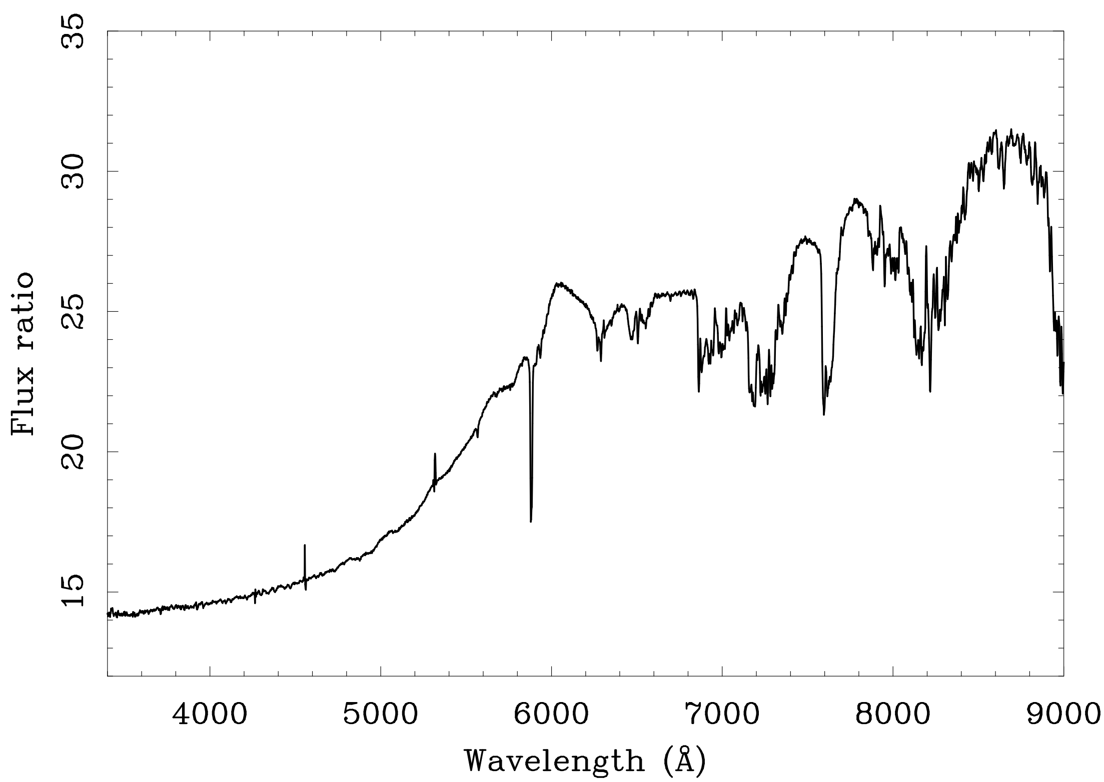

Figure 2: Ratio of the two CTIO twilight spectra used in the example calculation.

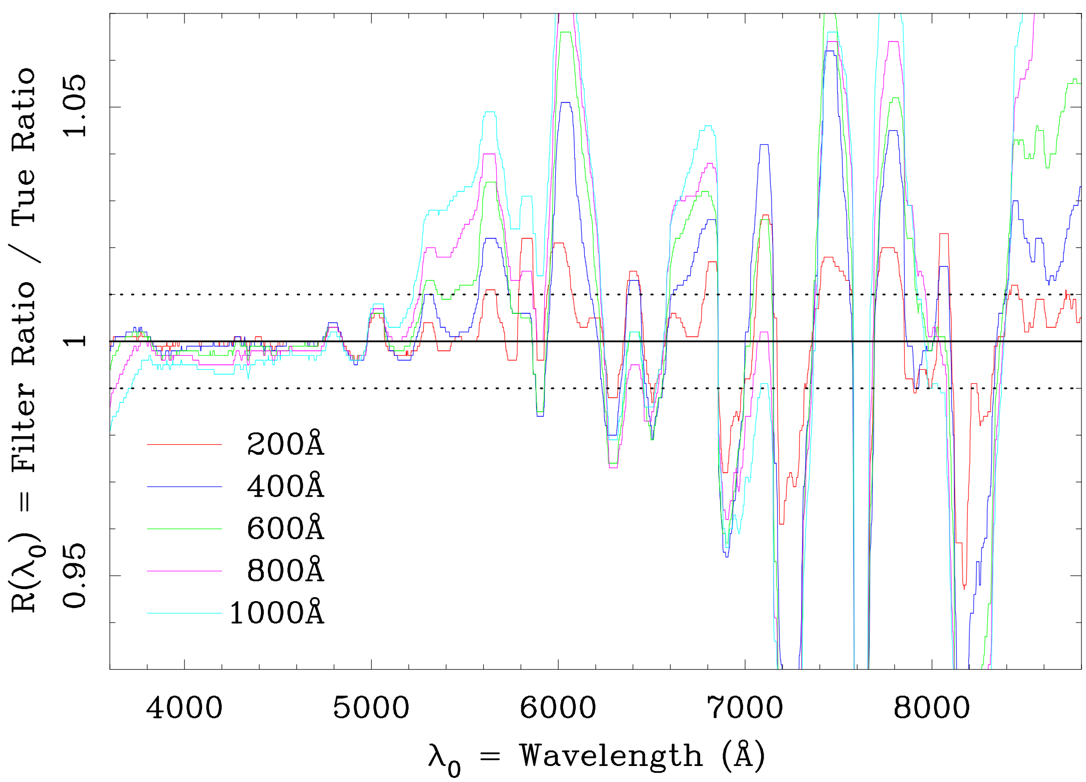

Figure 3: The value of $R(\lambda_0)$ versus wavelength λ_0 based on two twilight spectra, for a range of values of $\Delta\lambda = 200$Å, 400Å, 600Å, 800Å, and 1000Å. Twilights have the potential to be used for cross-calibration if $R(\lambda_0)$ is within 1% of the ideal value, $R(\lambda_0) = 1$. This range is enclosed by dotted horizontal lines. Note that the value of $R(\lambda_0)$ has been median-smoothed on a scale of 100Å to help with the presentation and to best highlight the regions where $R(\lambda_0)$ is not strongly sensitive to the exact value of λ_0.

only be determined using a linear ramp filter at wavelengths where $R(\lambda_0) = 1$ to better than 1%. Of the wavelengths satisfying this requirement, those where $R(\lambda_0)$ is stable are best.

As expected, Fig. 3 shows that as the wavelength resolution, $\Delta\lambda$, of the imaging channel becomes coarser, there are fewer wavelengths were the condition $R(\lambda_0) = 1 \pm 0.01$ is satisfied. Indeed, in the case of these two twilight spectra, the redder wavelengths can be calibrated at only a very few wavelengths even for $\Delta\lambda = 200$Å. In Memo #4 Emmanuel gives the example for correction of smooth extinction for $\Delta\lambda = 200$Å. Fig. 3 shows that cross-calibration at the locations of water bands is a problem, therefore extinction correction in these locations could be compromised.

Although it is certainly possible to obtain twilight spectra which match better than the two used in this example, it is also quite likely that on occasion there will be twilight spectra which disagree even more than these two. If one assumes that the only reason these two spectra are different is due to the differing sun altitude, one can calculate that the time window to obtain spectra which are no more dissimilar is less than 15 minutes. At the UH 2.2-m, only morning twilight will be available, so if we cannot observe during the correct < 15 minute window, cross-calibration will be compromised. Moreover, we can expect that any cirrus clouds will modify the spectra even further; this would occur on the same nights when we are relying most on obtaining extinction correction from the extinction stars.

3 Contrasting Example using a NIST Calibration Lamp

In the memo "SNfactory Spectrophotometry Requirements Document," I suggested the use of a NIST calibration lamp for the spectrograph-imager cross-calibration. There I also showed that either the lamp must be reasonably stable in spectral shape (temperature) or the imager filter $\Delta\lambda$ must not be too large (e.g. it was shown that a NIST lamp is sufficiently stable for a 2nd moment of the filter transmission of 400Å, or $\Delta\lambda \sim 1000$Å). To test this suggestion on an even footing with the twilight calibration, I have repeated the calculations described above using pairs of NIST lamp spectra. Figs. 4 and 5 show examples with the lamp temperatures differing by 5% and 1% (a NIST lamp can be stabilized to about 0.3%). This shows that a stabi-

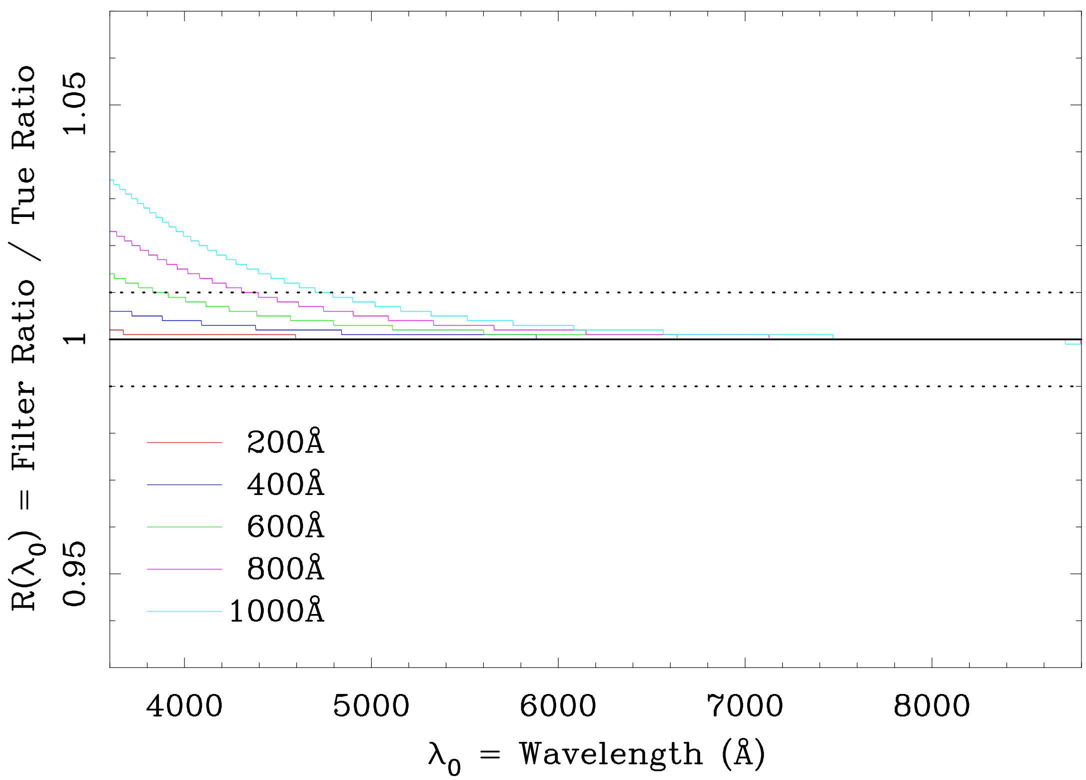

Figure 4: The value of $R(\lambda_0)$ versus wavelength λ_0 for two NIST lamp spectra with temperatures which differ by 5%, calculated for a range of values of $\Delta\lambda = 200$Å, 400Å, 600Å, 800Å, and 1000Å.

lized lamp is much more suitable as a cross-calibration source in terms of its spectral reproducibility. Interestingly, the NIST lamp is worst in the blue, where twilight works well, while it works very well in the red, where twilight performs poorly.

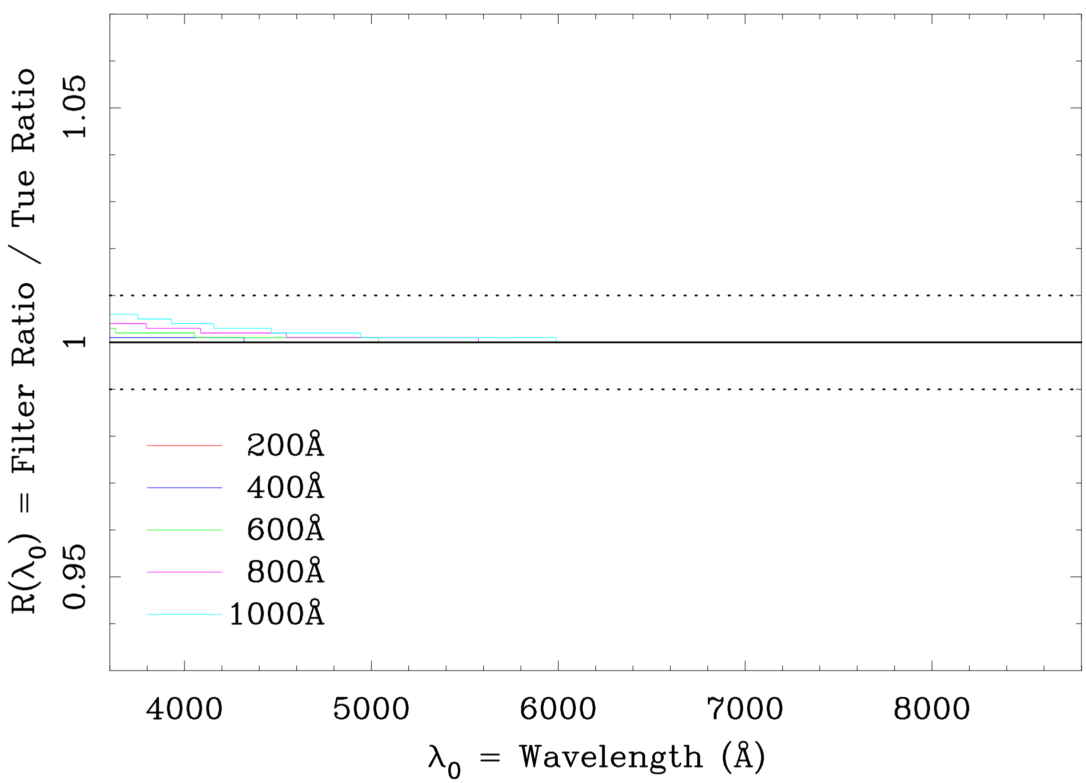

Figure 5: The value of $R(\lambda_0)$ versus wavelength λ_0 for two NIST lamp spectra with temperatures which differ by 1%, calculated for a range of values of $\Delta\lambda = 200$Å, 400Å, 600Å, 800Å, and 1000Å.