SNIFS memo 4 : Use of a linear ramp filter for the calibration channel (V1.0)

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1 Background of the problem

It has arisen from the scientific discussions that the photometric accuracy of SNIFS will be a major issue for the program. The target is to achieve 1% absolute photometry. This is a quite challenging goal which requires an accurate atmospheric transmission monitoring. In the very beginning of the project, Greg Aldering and Saul Perlmutter proposed to add to the spectrograph a parallel imaging channel (herafter photometric channel) which would monitor the atmospheric transparency using the stars in a large field ($\sim 5' \times 5'$) close to the spectrographic field. This simple approach was ruled out due to the chromatic dependency of the atmospheric transmission variation. Two solution were then possible:

- The first one consists in adding an objective prism in the photometric channel. This would allow to check the chromatic atmospheric variations. However, this solution leads to an oversized photometric channel, due to the required additional optics.
- The second one, proposed by Greg Aldering, is based on a multi-color filter located as close as possible to the detector of the photometric channel. In a document "SNfactory Spectrophotometry Requirements Document", Greg discuss the optimal choice of these filters and the methodology of the atmospheric transmission monitoring.

In this memo, I describe a variation of the multicolor filter approach, based on the use of a linear ramp filter (LRF).

2 Principle of the method

A ramp filter is a filter which bandpass depends on the position on the filter. In this study, I consider the case of a linear ramp filter. If the coordinates on the filter are (x, y) the bandwidth is constant but the central wavelength is a linear function of x: $\lambda_c = ax + b$. In our case λ_c will vary between 3200Åand 10000Å.

If this filter is in the focal plane, each star will be observed in a wavelength which depends on its position x on the detector. Its measured flux will then be:

$$F_*(x) = \int_{\lambda_c(x)-\frac{\Delta\lambda}{2}}^{\lambda_c(x)+\frac{\Delta\lambda}{2}} S(\lambda)T_i(\lambda)T_{atm}(\lambda)d\lambda$$

where $\lambda_c(x)$ is the central wavelength of the filter at position x, $\Delta\lambda$ the filter bandwidth, $S(\lambda)$ the star spectrum, $T_i(\lambda)$ the instrumental transmission and $T_{atm}(\lambda)$ the atmospheric transmission. If $\Delta\lambda$ was small enough to consider $S(\lambda)$, $T_i(\lambda)$ and $T_{atm}(\lambda)$ constant in the integration range, the measured flux would then be simply writen as:

$$F_*(x) = S(\lambda_c(x))T_i(\lambda_c(x))T_{atm}(\lambda_c(x))\Delta\lambda$$

If the instrumental transmission is constant from one night to another, the atmospheric transmission variation from one night to another at $\lambda_c(x)$ can be simply measured by the ratio between the measured flux of the star during the two nights. There must be enough stars in the field to sample the whole atmospheric transmission curve. This can be achieve only if $\Delta\lambda$ is large enough to reach a reasonable signal to noise ratio. However, we saw that the asumption that $S(\lambda)$, $T_i(\lambda)$ and $T_{atm}(\lambda)$ are constant in $\Delta\lambda$ is valid only if $\Delta\lambda$ is small enough. Anyway, this last asumption will certainly not be correct for a given star. The hope is that there will be enough stars, in order to average the errors due to this assumption.

I have performed simulations of an exposure through this kind of instrument to check if it can be used to monitor the atmospheric transmission.

3 Simulation of a photometric channel exposure

The simulation needs first an estimation of the star count as a function of the galactic latitude. I use a very simple approach: the Allen's "Astrophysical Quantities" third edition gives a table of the number of stars per square degrees brighter than a given magnitude m as a function of the galactic latitude b. I simply interpollate these values in the (m, b) plane for the simulation. For the fractions of stars in each spectral type, I also take the numbers of Allen. This is a quite rough model, but it is in relatively good agreement with the much more detailed one of Annie Robin (http://physique.obs-besancon.fr/modele/modele.html#simu), which perform a detailed modeling of the Galaxy to derive the star counts.

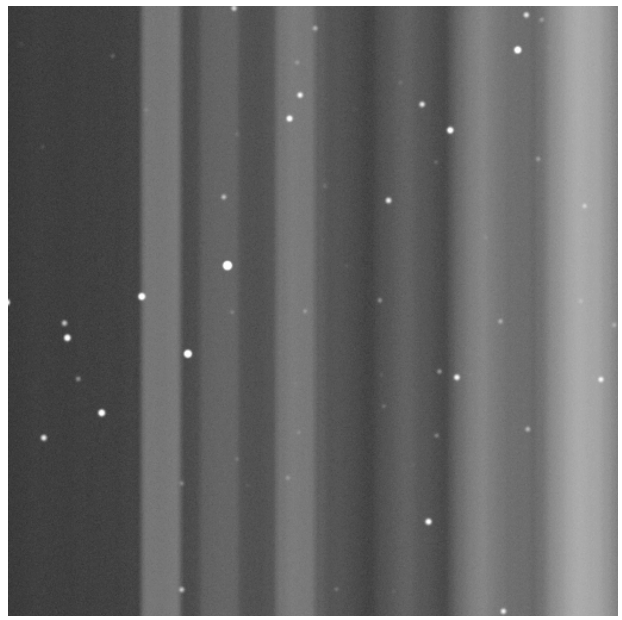

Figure 1: Raw exposure through a LRF of $\Delta\lambda = 200$Åat a galactic lattitude $b = 50^o$.

The resolution of the LRF and the galactic latitude of the field are input parameters of the simulation. In these simulation, I only consider Rayleigh scattering and aerosol diffusion. The 3 atmospheric parameters are then computed randomly for two different nights.

The stars magnitudes and spectral type are randomly computed using the Allen's data as mean. After several tests I chosed $\Delta\lambda = 200$Å. I only consider the stars which signal to noise is larger than 10. I assume a seeing of 0.8". The stellar spectra are aproximated by a black body function with a temperature given by the stellar type.

A typical exposure is given in figure1. The vertical bands correspond to the sky spectrum. This spectrum is easily evaluated by computing the median of all the rows. It can then be subtracted from the raw exposure to give the final photometric exposure (figure 2).

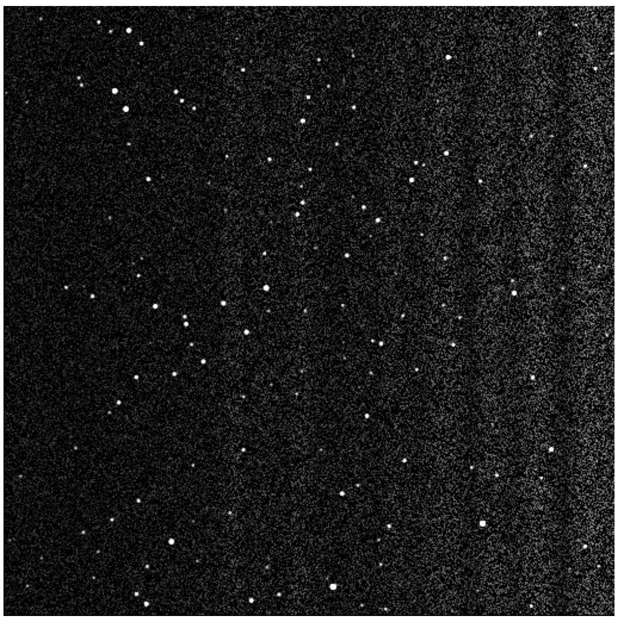

Figure 2: Sky subtracted exposure.

The ratio between the intensity of each star from one exposure to another (two different atmospheric parameters set) is computed in the simulation. The theoretical value of this ratio is also computed. In order to compare the theoretical curve with the data, one has to perform a fit on the data points. I tried several fitting functions and kept the following one:

$$T_{fit}(\lambda) = \exp(a_0 + a_1\lambda^{-1} + a_2\lambda^{-2} + a_3\lambda^{-3} + a_4\lambda^{-4})$$

The superposition of the measured points and the the fit is given in figure 3. The comparison

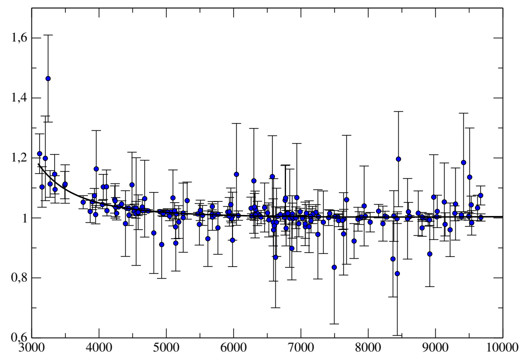

Figure 3: **Circles:** ratio between the observed flux of each star from one night to the other. **Solid line:** fit of the data (see text for the model function description).

between the fitted curve and the theoretical line is given in figure 4

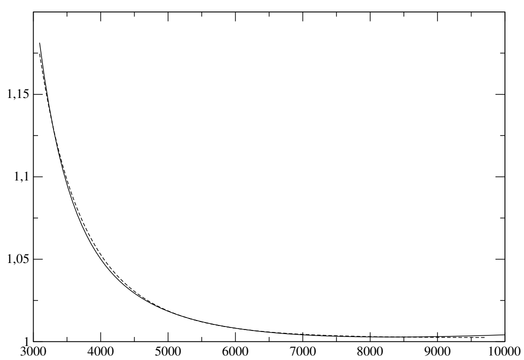

Figure 4: Comparison between the theoretical and measured atmospheric transmission curves. **Solid line:** Fitted ratio. **Dashed line:** Theoretical ratio.