A proposal for relative in-flight flux self-calibrations for spectro-photometric surveys

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Pheno2021, May 24-26 2021, Pittsburgh (USA)
Several experiments foresee large-scale redshift surveys of galaxies

**Image credits Euclid Consortium**

The Euclid near-infrared spectro-photometer

Calibrations are needed that can be performed on the ground (instrumental effects) and in orbit (telescope optics)
• The same sources in the sky can be recorded in different positions on the focal plane in different pointings. The recorded counts may vary
\[ \text{Id}_k (\xi_k, \eta_k) \rightarrow \text{flux}_i (x_i, y_i) \]
\[ \text{Id}_k (\xi_k, \eta_k) \rightarrow \text{flux}_j (x_j, y_j) \]
• One needs to determine the detector response function \( f \).

• A method based on iterative minimizations was proposed by R. Holmes, D.W. Hogg, H.-W. Rix in *Publications of the Astronomical Society of the Pacific, Volume 124, Number 921*.
• Here we generalize the method
  • Usage of an arbitrary basis for the decomposition of the reconstruction function
  • Evaluation of uncertainties through the complete covariance matrix
• We aim at determining the relative response function, wrt a reference point: we chose the central point of the focal plane (0,0)
  • A calibration using sources with known fluxes can then provide the overall scale factor.

• The reconstructed response function is parametrized to account for
  • A smooth variation due to the telescope optics
  • on top of possible discontinuous effects due to the use of detectors with slightly difference performances in the different sectors

\[
\hat{f}(x, y | q, g) = \sum_{\ell=0}^{N} q_\ell \, w_\ell(x, y) \sum_s g_s \, \Theta_s(x, y)
\]

Linear combination over a basis in a space with 2D continuous functions

Term specific for each sector, with potentially different gains

• The basis is arbitrary. Here we tested 3 cases: the set of powers, the Legendre polynomials, and the Fourier basis
Exposures in the sky

Observations in the focal plane

Reconstructed response

\[ \hat{\chi}^2 = \sum_k \sum_i \frac{c_k(i) - \hat{f}(x_k(i), y_k(i) | q, g) r_k t_i}{\sigma^2_k(i)} \]

- Observed count of the k-th source in the i-th pointing
- Expected count of the k-th source in the i-th pointing, given response with coefficients q and gain g
- Count variance from data (Neyman $\chi^2$) = obs count + sub noise

Exposure time
Source rate
• We performed **mock-up tests** with randomly generated sky catalogues
  • In each test, 500 different synthetic calibration surveys are randomly produced.
  • Focal plane modeling and general configuration: simplified wrt a real survey
  • Distribution of stellar magnitudes from the Besançon synthetic model of the Galaxy*
    (12<mag$_{AB}$<17)

• With the tests
  • We verified the lack of biases in the reconstruction algorithm
  • We performed a **statistical analysis** of the reconstruction goodness in function of the **mean n. of sources** in FoV and **n. of exposures**
  • We studied the convergence of the reconstructed function to an arbitrarily complicated instrument response. Plausible **input** function: radial decrease (**Power**) + oscillations (**Fourier**)
  • We established that the **Legendre basis** for the reconstruction yields the best computation performances

* [https://model.obs-besancon.fr](https://model.obs-besancon.fr)
Verification of the absence of biases
Definition of metrics to quantify the goodness of the reconstruction

- **Maximum absolute difference** (MAD)
  \[ \max |f_{true}(x_i, y_i) - f_{reco}(x_i, y_i)| \text{ on Focal Plane} \]

- **Cumulative absolute difference** (CAD)
  integral of \[ |f_{true}(x_i, y_i) - f_{reco}(x_i, y_i)| \text{ on FP} \]

- **Unusable fraction (threshold)** (UF(th%))
  fraction of FP where \[ |f_{true}(x_i, y_i) - f_{reco}(x_i, y_i)| > \text{threshold} \]

Customizable threshold: we used 70%
Figures of merit as a function of the total number of degrees of freedom
Trend plots of the goodness metrics as a function of the total number of degrees of freedom.
Conclusions and outlook

• We presented a technique for the in-flight relative flux self-calibration method, which generalizes the procedure outlined in R. Holmes, D.W. Hogg, H.-W. Rix in *PASP* 124, 921.
  • The method is based on the repeated observations of sources in different positions of the focal plane, following a **random observation pattern**
  • $\chi^2$ statistic $\rightarrow$ **unbiased inference** of the sources count rates and of the reconstructed relative response function
  • Mock-up tests to study the **convergence** of the reconstructed function to an arbitrarily complicated instrument response
  • The number of repeated observations drives the goodness of the reconstruction $\rightarrow$ **a small number of exposures can be compensated by a large number of sources in the field of view**, or vice-versa
  • If the number of repeated observations is sufficiently high, **it is possible to reconstruct the relative instrument response function with high accuracy, without any prior knowledge.**

• The work has been submitted to Publications of the Astronomical Society of the Pacific.
  • Possible developments: more realistic detector models