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

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Pheno2021, May 24-26 2021, Pittsburgh (USA)

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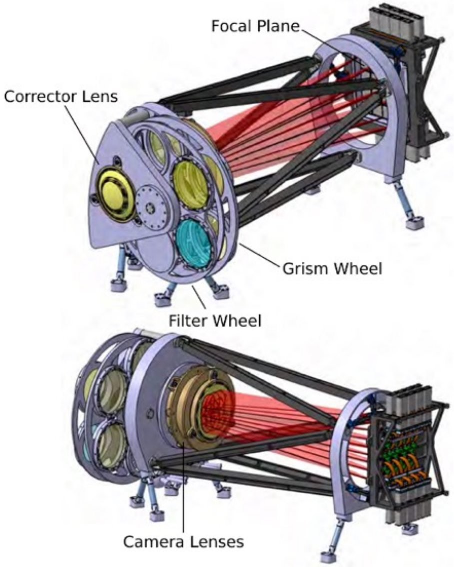
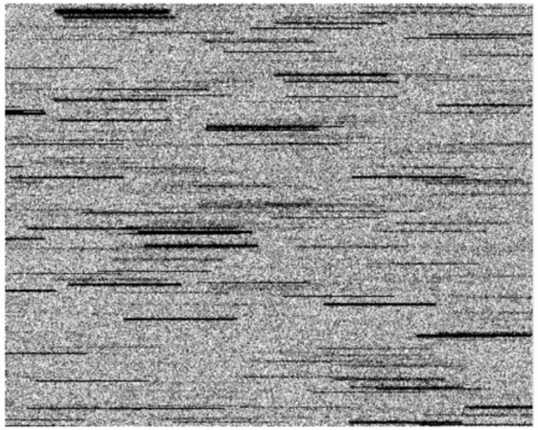
Several experiments foresee large-scale redshift surveys of galaxies

Image credits Euclid Consortium

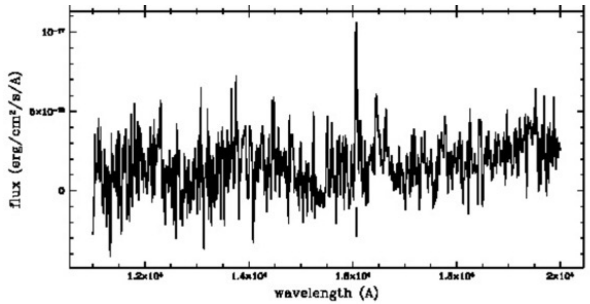
From Euclid Redbook ESA/SRE(2011)12



The Euclid near-infrared spectro-photometer

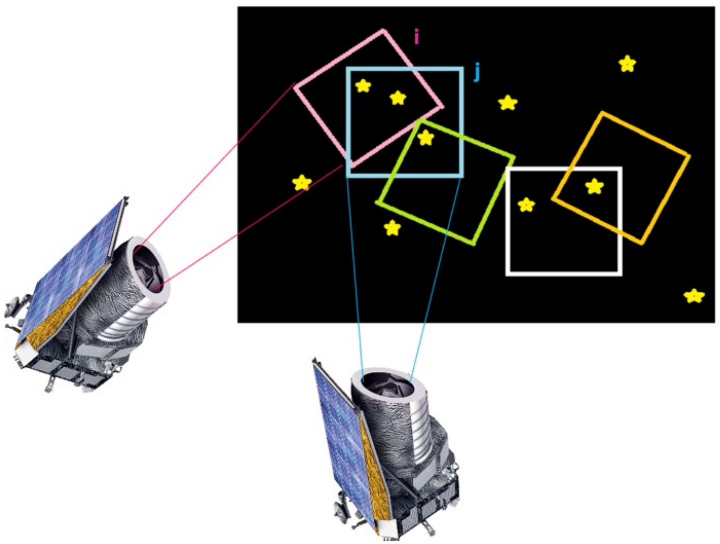


Simulation of a slitless observation



Simulated spectrum with a Hα line

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
  $Id_k\ (\xi_k\ , \eta_k) \to flux_i\ (x_i, y_i)$
  $Id_k\ (\xi_k\ , \eta_k) \to flux_j\ (x_j, y_j)$
- 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 detemining 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

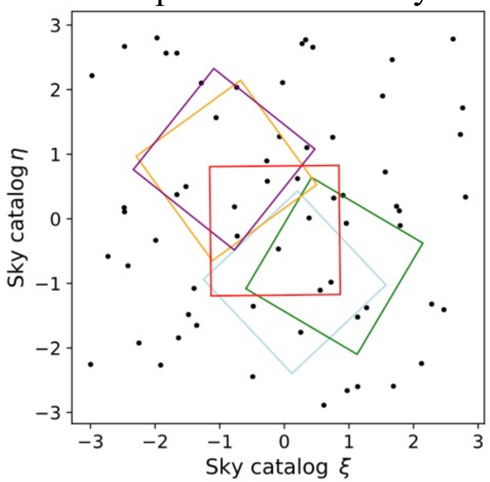
$$\hat{f}(x, y\,|\boldsymbol{q}, \boldsymbol{g}) = \sum_{\ell=0}^{N} q_\ell\, w_\ell(x, y) \sum_s g_s \Theta_s(x, y)$$

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

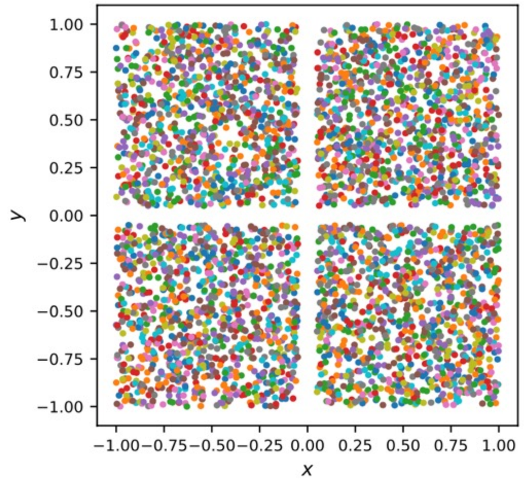
Term speficic for each sector, with potentially different gains

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

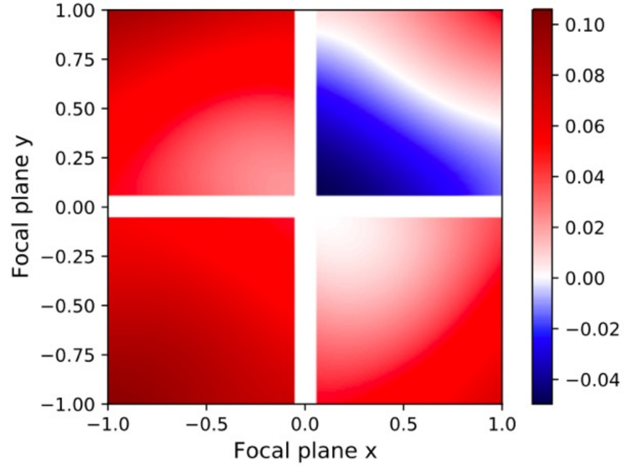
Exposures in the sky



Observations in the focal plane



Reconstructed response



$$\hat{\chi}^2 = \sum_k \sum_i^{n_k} \frac{\left[c_{k(i)} - \hat{f}(x_{k(i)}, y_{k(i)} \,|\boldsymbol{q}, \boldsymbol{g}) r_k t_i\right]^2}{\sigma^2_{k(i)}}$$

Exposure time

Source rate

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

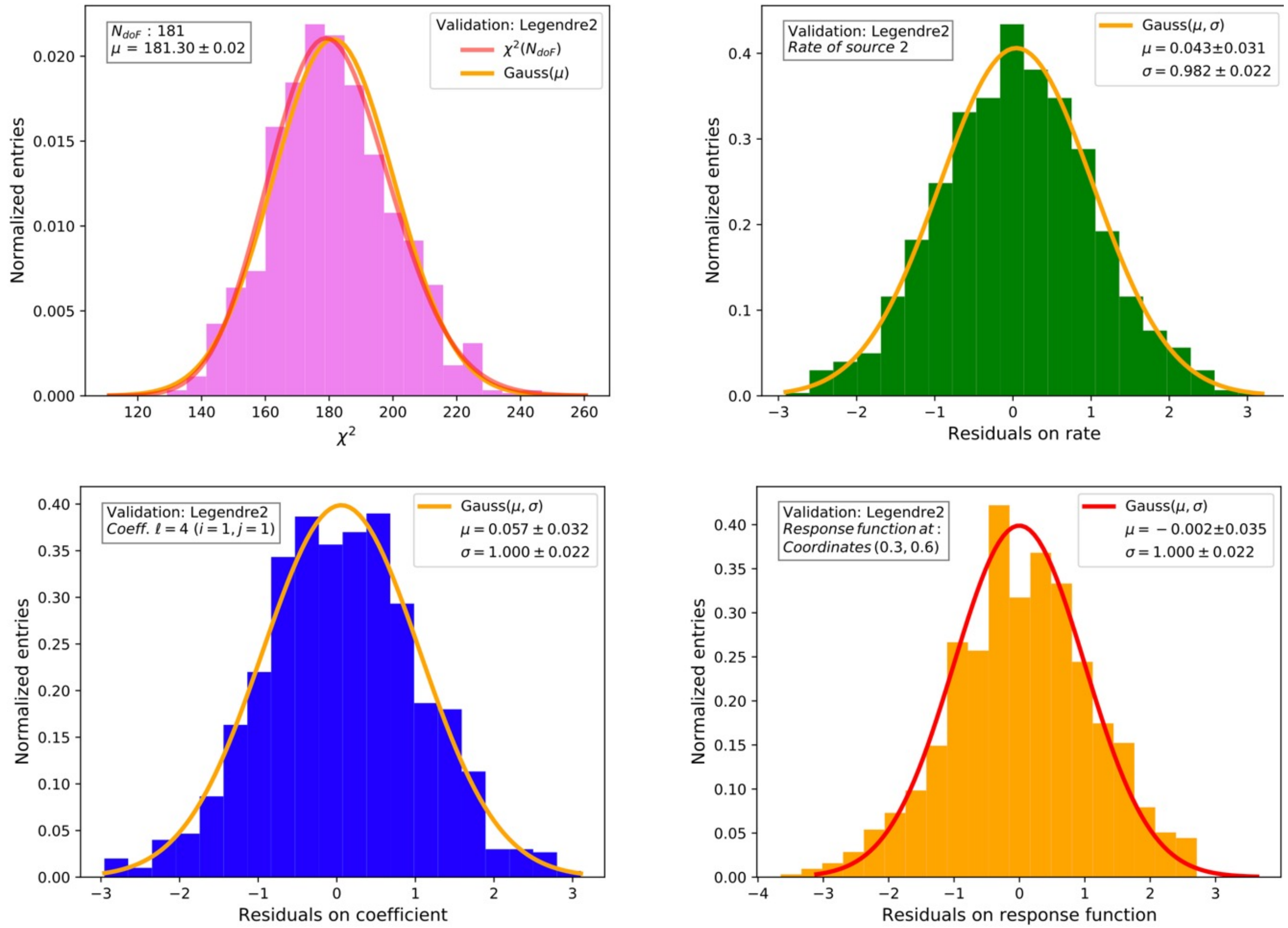
Count variance from data (Neyman χ^2) = obs count + sub noise

- 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

Verification of the absense of biases



Definition of metrics to quantify the goodness of the reconstruction

- **Maximum absolute difference (MAD)**

max $|f_{true}(xi, yi) - f_{reco}(xi, yi)|$ on Focal Plane

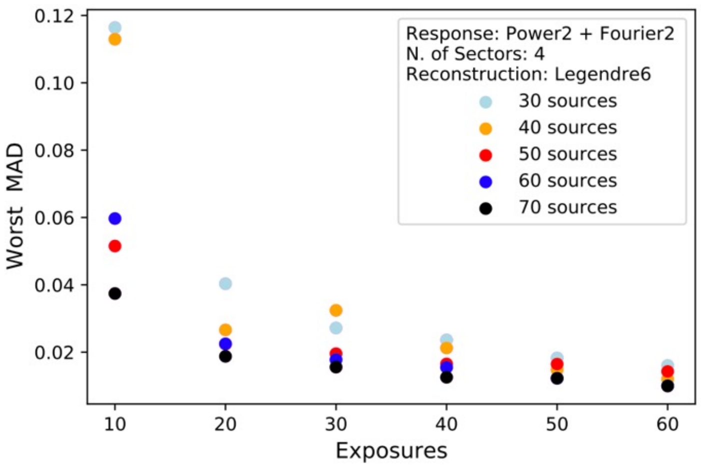
- **Cumulative absolute difference (CAD)**

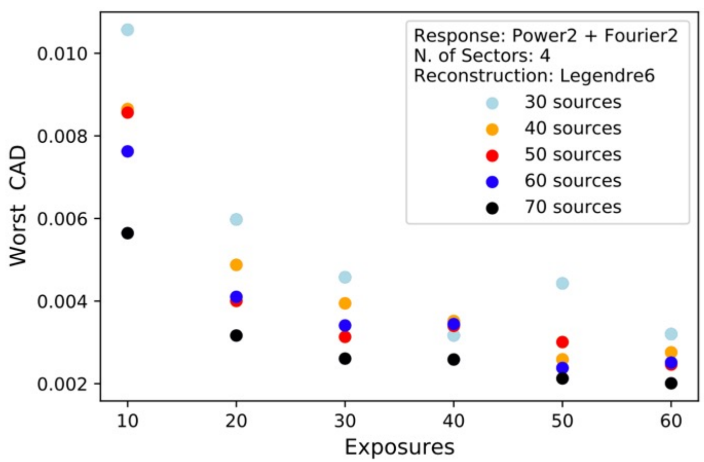
integral of $|f_{true}(xi, yi) - f_{reco}(xi, yi)|$ on FP

Customizable threshold: we used 70%

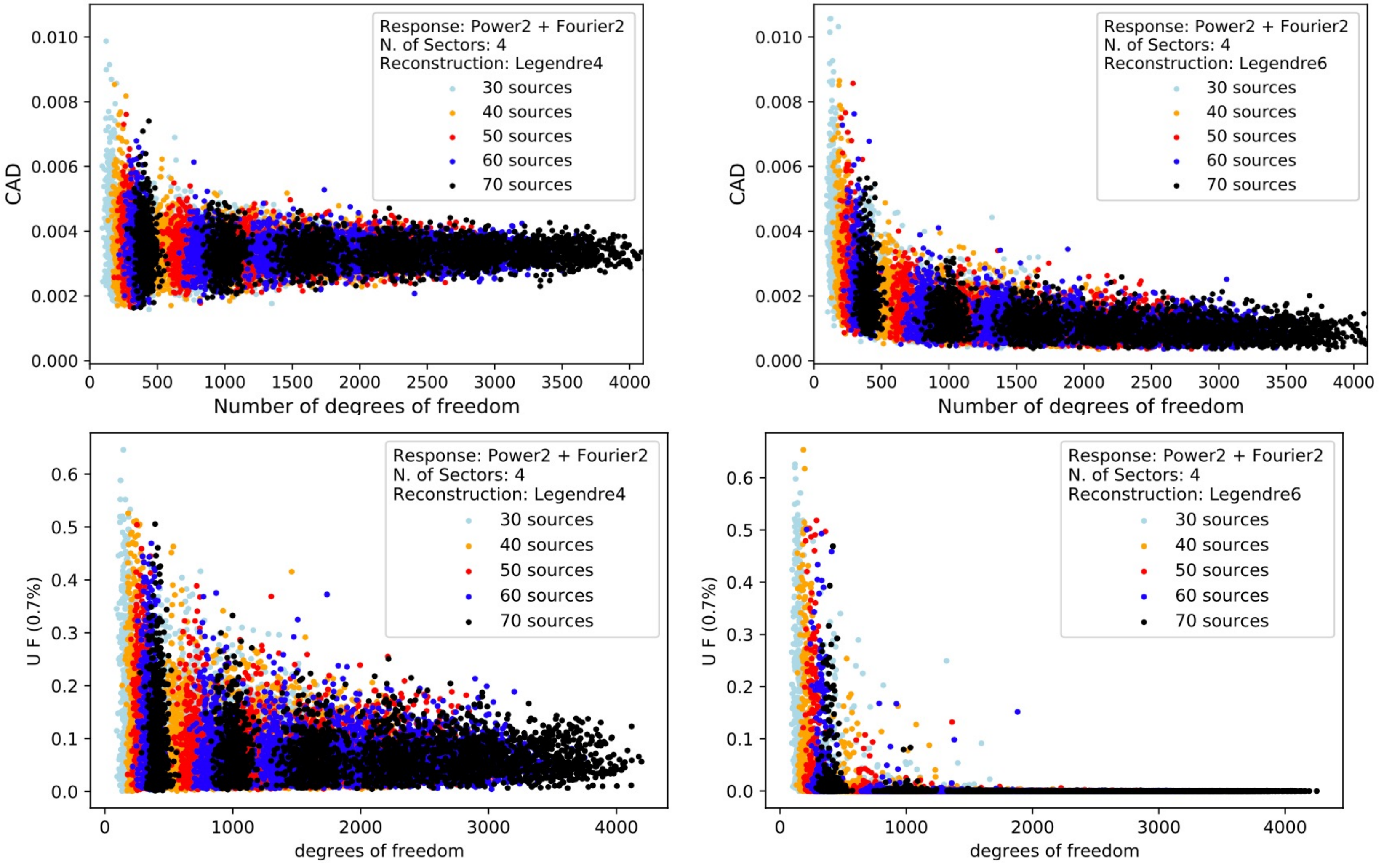
- **Unusable fraction (threshold) (UF(th%))**

fraction of FP where $|f_{true}(xi, yi) - f_{reco}(xi, yi)|$ > threshold

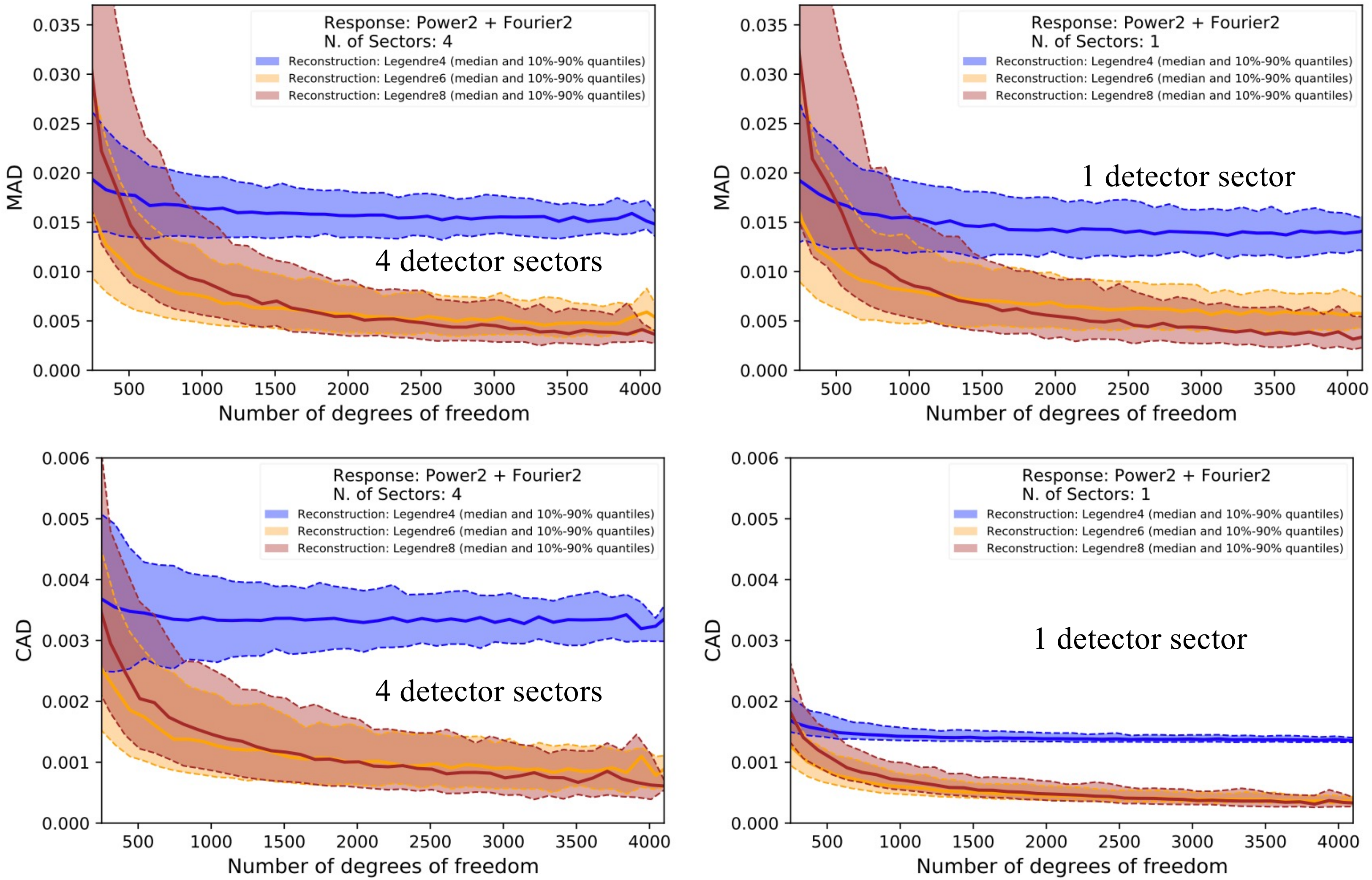




Figures of merit as a function of the total number of degrees of freedom



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**
  - χ^2 statistic -> **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 -> **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.
  - arXiv:2103.15512 largely based on Ilaria Risso's thesis
  - Possible developments: more realistic detector models