Optimizing Large Scale Imaging Surveys for Relative Photometric Calibration, the Euclid Dark Energy Mission as an Example

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ABSTRACT

In this paper we show that, with due care given to the observing strategy, it will be possible to accurately constrain the relative photometric calibration of instruments used in large imaging surveys with their science data alone. We create end-to-end simulations of an imaging survey, which produces simulated datasets from mock observations of a synthetic sky according to a defined survey strategy. These catalog based simulations include realistic measurement uncertainties and a complex, position dependent instrument response. We then use a self-calibration technique to recover the relative instrument response by fitting an model that best explains the survey dataset, based on the multiple observations of (non-varying) sources at different focal plane positions. By considering four simple survey strategies we find that, with a correct redundancy built into the survey strategy, it is possible to accurately constrain the relative photometric response of an imaging instrument, and therefore the relative calibration of the resulting dataset. The majority of the remaining post self-calibration errors are due to the limitations in the basis used to model the relative instrument response. We find that returning the same sources to very different focal plane positions is the key property of a survey strategy that is required for an accurate calibration. From the results of this work, we are able to highlight an important point for those considering the design of large scale imaging surveys: depart from a regular tiling of the sky and return the same sources to very different focal plane positions.

Subject headings: Relative Photometric Calibration: Imaging Survey: Euclid

1. Introduction

Astronomers tend to think in terms of taking science data and calibration data separately. The former is used for science and the latter is used to constrain instrument parameters like the flat-field, the dark currents and so-on. But typically far more photons are collected during science exposures; are these not incredibly constraining on the calibration themselves? Indeed, in the retrospective photometric calibration of the Sloan Digital Sky Survey data (SDSS) much more calibration information was obtained from the science data than the calibration data (Padmanabhan et al. 2008). But, of course, the SDSS imaging strategy had to be adjusted to make this calibration work: good redundancy is required in the data stream, and a redundancy of a very specific kind.

In this paper, we argue that the next generation of large surveys should have their observation strategies optimized from the very start with this "self-calibration" in mind. We focus here on the relative photometric calibration of a typical imaging instrument only, although we also suspect that similar techniques could be used to constrain many other calibration parameters. This technique utilizes the multiple measurements of (non-varying) sources at different focal plane positions and at different times within the survey to constrain the relative instrument response by requiring that they yield the same count values. Through end-to-end – catalog level – survey simulations[1], we aim to identify the important properties of survey strategies that makes them advantageous for this kind of self-calibration.

These simulations include a complex, position dependent instrument response; through mock observations of a synthetic sky, according to a defined survey strategy, we construct a realistic survey dataset. We then fit a (different) instrument response model that best

[1]All of the code used in this work is publicly available at XX.

describes this dataset. By comparing the *fitted* instrument response to the *true* instrument response we are able to assess the performance of the self-calibration procedure with different survey strategies. There is a degeneracy in this problem: the self-calibration procedure is only able to fit for a *relative* instrument response. We have no way of know, for example, if all the sources are uniformly fainter, or if the instrument sensitivity is uniformly lower.

In Section 2 we introduce the simulation chain constructed to produce the realistic survey datasets. Section 3 goes onto to detail the self-calibration procedure. In Section 4 we focus on four simple survey strategies, which allow us to draw conclusions on the performance of the self-calibration procedure with different survey properties. We do not produced pixelated images; instead we concentrate on catalog level simulations with realistic measurement uncertainties. Complex effects are included in the simulations that are not precisely modeled at the analysis stage, in order to simulate the effects of unknown systematic errors within the dataset.

2. Survey Dataset Simulations

We have constructed an end-to-end simulation chain that produces a realistic imaging dataset from a specified survey strategy. Simulation parameters are kept intentionally flexible, so that the sensitivity of the self-calibration procedure to different parameters can be investigated. The simulations are split into a number of steps. First, a synthetic sky is generated based on the specified simulation parameters (density of sources, magnitude ranges). With a given pointing, single mock observations are performed on this sky, again here with tunable simulation parameters, such as the instrument response model and the the noise model. The final step is the build up of the survey wide dataset from multiple single observations taken according to the prescribed survey strategy. In this section, we detail the assumptions and methods used in each of these steps.

2.1. The Synthetic Sky

We generate a representative synthetic sky based on realistic object densities in the AB magnitude range $m_{\rm min} = 17$ to $m_{\rm max} = 22$ mag$_{\rm AB}$, with these limits chosen to be consistent with the saturation and 10σ limits of deep, space-based, near-infrared survey. Sources are generated with random coordinates (uniformly distributed within the sky region being investigated) and with random magnitudes m distributed according to

$$\log_{10} \frac{\mathrm{d}N}{\mathrm{d}m\,\mathrm{d}\Omega} = a + b\,m + c\,m^2 \quad , \tag{1}$$

where $\frac{\mathrm{d}N}{\mathrm{d}m\,\mathrm{d}\Omega}$ is the density of sources N per unit magnitude m and per unit solid angle Ω, and a, b and c are model parameters. Even though our simulations make no distinction between galaxies and stars, the values of the parameters are found from fitting the Y-band galaxy populations reported in Windhorst et al. (2011) **?** only. These parameters were $a = -13.05$, $b = 1.25$ and $c = -0.02$. We intentionally omit the stellar population, so that the conclusions drawn from these simulations are independent of the final position of the survey area on the sky. The source magnitudes m are related to the source fluxes s simply by: $m = 22.5 - 2.5 \log_{10}(s)$, where the 22.5 puts the fluxes in units of nanomaggies (nmgy).

2.2. A Single Exposure

FoV

2.3. The Complete Survey

3. The Self-Calibration Technique

4. The Simple Survey Strategies

5. Discussion

In this paper, we have considered the optimization of survey strategies for calibrating the relative photometric response of an instrument, but we feel there are many more calibration parameters that can be constrained for this method. For example, the optical distortion of an instrument could also be constrained with such a method, although we concede that the properties of a survey strategy that makes them good for one calibration, may not be the same as that for another; ultimately a trade-off would need to be performed.

6. Acknowledgments

We are grateful to

REFERENCES

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Table 1. Sample table taken from ?

POS	chip	ID	X	Y	RA	DEC	IAU$\pm$ δ IAU	IAP1$\pm$ δ IAP1	IAP2 $\pm$ δ IAP2	star	E	Comment
0	2	1	1370.99	57.35	6.651120	17.131149	21.344$\pm$0.006	2 4.385$\pm$0.016	23.528$\pm$0.013	0.0	9	-
0	2	2	1476.62	8.03	6.651480	17.129572	21.641$\pm$0.005	2 3.141$\pm$0.007	22.007$\pm$0.004	0.0	9	-
0	2	3	1079.62	28.92	6.652430	17.135000	23.953$\pm$0.030	2 4.890$\pm$0.023	24.240$\pm$0.023	0.0	-	-
0	2	4	114.58	21.22	6.655560	17.148020	23.801$\pm$0.025	2 5.039$\pm$0.026	24.112$\pm$0.021	0.0	-	-
0	2	5	46.78	19.46	6.655800	17.148932	23.012$\pm$0.012	2 3.924$\pm$0.012	23.282$\pm$0.011	0.0	-	-
0	2	6	1441.84	16.16	6.651480	17.130072	24.393$\pm$0.045	2 6.099$\pm$0.062	25.119$\pm$0.049	0.0	-	-
0	2	7	205.43	3.96	6.655520	17.146742	24.424$\pm$0.032	2 5.028$\pm$0.025	24.597$\pm$0.027	0.0	-	-
0	2	8	1321.63	9.76	6.651950	17.131672	22.189$\pm$0.011	2 4.743$\pm$0.021	23.298$\pm$0.011	0.0	4	edge

Note. — Table 1 is published in its entirety in the electronic edition of the *Astrophysical Journal*. A portion is shown here for guidance regarding its form and content.

[a]Sample footnote for table 1 that was generated with the deluxetable environment

[b]Another sample footnote for table 1

Table 2. Literature Data for Program Stars

Star	V	b−y	m_1	c_1	ref	T_{eff}	log g	v_{turb}	[Fe/H]	ref
HD 97	9.7	0.51	0.15	0.35	2	···	···	···	−1.50	2
						5015	···	···	−1.50	10
HD 2665	7.7	0.54	0.09	0.34	2	···	···	···	−2.30	2
						5000	2.50	2.4	−1.99	5
						5120	3.00	2.0	−1.69	7
						4980	···	···	−2.05	10
HD 4306	9.0	0.52	0.05	0.35	20, 2	···	···	···	−2.70	2
						5000	1.75	2.0	−2.70	13
						5000	1.50	1.8	−2.65	14
						4950	2.10	2.0	−2.92	8
						5000	2.25	2.0	−2.83	18
						···	···	···	−2.80	21
						4930	···	···	−2.45	10
HD 5426	9.6	0.50	0.08	0.34	2	···	···	···	−2.30	2
HD 6755	7.7	0.49	0.12	0.28	20, 2	···	···	···	−1.70	2
						5200	2.50	2.4	−1.56	5
						5260	3.00	2.7	−1.67	7
						···	···	···	−1.58	21
						5200	···	···	−1.80	10
						4600	···	···	−2.75	10
HD 94028	8.2	0.34	0.08	0.25	20	5795	4.00	···	−1.70	22

Table 2—Continued

Star	V	b−y	m_1	c_1	ref	T_{eff}	log g	v_{turb}	[Fe/H]	ref
						5860	···	···	−1.70	4
						5910	3.80	···	−1.76	15
						5800	···	···	−1.67	17
						5902	···	···	−1.50	11
						5900	···	···	−1.57	3
						···	···	···	−1.32	21
HD 97916	9.2	0.29	0.10	0.41	20	6125	4.00	···	−1.10	22
						6160	···	···	−1.39	3
						6240	3.70	···	−1.28	15
						5950	···	···	−1.50	17
						6204	···	···	−1.36	11
This is a cut-in head										
+26°2606	9.7	0.34	0.05	0.28	20,11	5980	···	···	< −2.20	19
						5950	···	···	−2.89	24
+26°3578	9.4	0.31	0.05	0.37	20,11	5830	···	···	−2.60	4
						5800	···	···	−2.62	17
						6177	···	···	−2.51	11
						6000	3.25	···	−2.20	22
						6140	3.50	···	−2.57	15

Table 2—Continued

Star	V	b−y	m_1	c_1	ref	T_{eff}	log g	v_{turb}	[Fe/H]	ref
+30°2611	9.2	0.82	0.33	0.55	2	···	···	···	−1.70	2
						4400	1.80	···	−1.70	12
						4400	0.90	1.7	−1.20	14
						4260	···	···	−1.55	10
+37°1458	8.9	0.44	0.07	0.22	20,11	5296	···	···	−2.39	11
						5420	···	···	−2.43	3
+58°1218	10.0	0.51	0.03	0.36	2	···	···	···	−2.80	2
						5000	1.10	2.2	−2.71	14
						5000	2.20	1.8	−2.46	5
						4980	···	···	−2.55	10
+72°0094	10.2	0.31	0.09	0.26	12	6160	···	···	−1.80	19
I'm a side head:										
G5–36	10.8	0.40	0.07	0.28	20	···	···	···	−1.19	21
G18–54	10.7	0.37	0.08	0.28	20	···	···	···	−1.34	21
G20–08	9.9	0.36	0.05	0.25	20,11	5849	···	···	−2.59	11
						···	···	···	−2.03	21
G20–15	10.6	0.45	0.03	0.27	20,11	5657	···	···	−2.00	11
						6020	···	···	−1.56	3
						···	···	···	−1.58	21
G21–22	10.7	0.38	0.07	0.27	20,11	···	···	···	−1.23	21
G24–03	10.5	0.36	0.06	0.27	20,11	5866	···	···	−1.78	11

Table 2—Continued

Star	V	b−y	m_1	c_1	ref	T_{eff}	log g	v_{turb}	[Fe/H]	ref
						···	···	···	−1.70	21
G30–52	8.6	0.50	0.25	0.27	11	4757	···	···	−2.12	11
						4880	···	···	−2.14	3
G33–09	10.6	0.41	0.10	0.28	20	5575	···	···	−1.48	11
G66–22	10.5	0.46	0.16	0.28	11	5060	···	···	−1.77	3
						···	···	···	−1.04	21
G90–03	10.4	0.37	0.04	0.29	20	···	···	···	−2.01	21
LP 608–62[a]	10.5	0.30	0.07	0.35	11	6250	···	···	−2.70	4

[a]Star LP 608–62 is also known as BD+1°2341p. We will make this footnote extra long so that it extends over two lines.

References. — (1) Barbuy, Spite, & Spite 1985; (2) Bond 1980; (3) Carbon et al. 1987; (4) Hobbs & Duncan 1987; (5) Gilroy et al. 1988: (6) Gratton & Ortolani 1986; (7) Gratton & Sneden 1987; (8) Gratton & Sneden (1988); (9) Gratton & Sneden 1991; (10) Kraft et al. 1982; (11) LCL, or Laird, 1990; (12) Leep & Wallerstein 1981; (13) Luck & Bond 1981; (14) Luck & Bond 1985; (15) Magain 1987; (16) Magain 1989; (17) Peterson 1981; (18) Peterson, Kurucz, & Carney 1990; (19) RMB; (20) Schuster & Nissen 1988; (21) Schuster & Nissen 1989b; (22) Spite

et al. 1984; (23) Spite & Spite 1986; (24) Hobbs & Thorburn 1991; (25) Hobbs et al. 1991; (26) Olsen 1983.