Monthly Notices of the ROYAL ASTRONOMICAL SOCIETY
MNRAS **438,** 1256–1266 (2014) doi:10.1093/mnras/stt2272
Advance Access publication 2013 December 19

Removal of systematics in photometric measurements: static and rotating illumination corrections in FORS2@VLT data

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Accepted 2013 November 21. Received 2013 November 21; in original form 2013 September 13

ABSTRACT

Images taken with modern detectors require calibration via flat fielding to obtain the same flux scale across the whole image. One method for obtaining the best possible flat-fielding accuracy is to derive a photometric model from dithered stellar observations. A large variety of effects have been taken into account in such modelling. Recently, Moehler et al. discovered systematic variations in available flat frames for the European Southern Observatory's FOcal Reducer and low-dispersion Spectrographs (FORS) instrument that change with the orientation of the projected image on the sky. The effect on photometry is large compared to other systematic effects that have already been taken into account. In this paper, we present a correction method for this effect: a generalization of the fitting procedure of Bramich & Freudling to include a polynomial representation of rotating flat-fields. We then applied the method to the specific case of FORS2 photometric observations of a series of standard star fields, and provide parametrized solutions that can be applied by the users. We found polynomial coefficients to describe the static and rotating large-scale systematic flat-field variations across the FORS2 field of view. Applying these coefficients to FORS2 data, the systematic changes in the flux scale across FORS2 images can be improved by ∼1 to ∼2 per cent of the total flux. This represents a significant improvement in the era of large-scale surveys, which require homogeneous photometry at the 1 per cent level or better.

Key words: instrumentation: detectors – methods: data analysis – methods: observational – methods: statistical.

1 INTRODUCTION

The problem of the calibration of an ensemble of photometric data can be divided into two parts (Padmanabhan et al. 2008; Betoule et al. 2013): namely a *relative* calibration, where all of the data are calibrated to the same photometric scale with arbitrary flux units, and an *absolute* calibration, where the photometric scale is calibrated into physical flux units (e.g. J m^{-2} s^{-1}) via comparison to a particular object (or set of objects) with known magnitudes. The relative calibration can depend on a slew of parameters pertinent to how the photometric data were obtained (e.g. colour dependence, atmospheric transparency, detector coordinates, image quality, etc.) and, a priori, it is not always clear which set of parameters best describe the relative calibration. The additional step of absolute calibration boils down to the determination of an extra parameter (zero-point), to convert the measurements into physical flux units.

Early papers on the photometric calibration methodology defined the modelling procedures required for a relative calibration (Harris, Fitzgerald & Reed 1981; Popper 1982; Reed & Fitzgerald 1982; Manfroid & Heck 1983; Honeycutt 1992). These works considered photometric calibration models with relative zero-points, extinction and colour terms combined with time dependence of the coefficients. They also considered the analysis of inhomogeneous observations of overlapping fields from potentially different detectors for a mix of standard and non-standard stars (i.e. non-variable stars with and without standard magnitudes, respectively).

The process of flat-fielding is required to calibrate images taken with modern detectors. This is achieved in practice by observing a uniformly illuminated source such as the twilight sky or a flat-field screen. Images of the uniform source, called flat frames, then record the sensitivity variations of the combined telescope/camera/detector system including the high-spatial-frequency pixel-to-pixel variations and the lower-spatial-frequency variations caused by out-of-focus dust shadows, etc. However, flat-fielding performed in this way does not correct perfectly for the sensitivity variations, especially for the larger scale variations. This is usually due to undesired effects present in the flat frames such as the central light (or sky) concentration or non-uniform illumination, but it may also be due to the different spectral energy distributions of

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the flat-field source and the astronomical objects which are to be measured.

Manfroid (1995) introduced the concept of performing a correction to the flat-field calibration (referred to as an 'illumination correction') by using the measured star magnitudes. By using the stars to perform (at least part of) the flat-fielding, many of the problems with using flat frames are avoided. The illumination correction introduces terms into the photometric calibration model that are a function of detector coordinates. For the purposes of this paper, we refer to this as a *static illumination correction*.

With the advent of large-scale surveys which require homogeneous photometry at the 1 per cent level or better, the size of photometric modelling problems has exploded. Padmanabhan et al. (2008) presented a photometric calibration model for Sloan Digital Sky Survey data on a scale many times larger than had been seen before with $\sim 3 \times 10^7$ calibration data points, $\sim 10^7$ star mean magnitudes to be determined and ~ 2000 calibration parameters. The Supernova Legacy Survey followed suit (Regnault et al. 2009) and they also developed a tractable way of solving for all of the parameters in the photometric models, including the star mean magnitudes for the non-standard stars, by using a single step in the least-squares solution (see also Schlafly et al. 2012). Most large surveys now regularly include all of the terms mentioned previously in the photometric model. In terms of photometric calibration modelling, a wide range of effects have already been considered in the literature, including relatively obscure effects that are only significant at the millimagnitude level (e.g. intrapixel photometric sensitivity maps; Piterman & Ninkov 2002).

However, what has not been discussed in the literature is how to include in the photometric calibration model a flat-field correction that rotates with an instrument component. From now on, we refer to this as a *rotating illumination correction*. The motivation for modelling a rotating illumination correction comes from the work of Moehler et al. (2010, hereafter Paper I), where they found that both of ESO's FOcal Reducer and low-dispersion Spectrographs (FORS; Appenzeller et al. 1998) instruments at the Very Large Telescope (VLT) produce twilight flats with a fixed large-scale structure component plus another large-scale structure that rotates with the field rotator; this rotating component was further tracked down to being caused by the linear atmospheric dispersion corrector (LADC). The rotating flat-field structure has the potential to degrade the photometric accuracy by adding a large systematic error of up to ~ 4 per cent to broad-band observations in the case of FORS. Although in Paper I we suggested several ad hoc solutions to this problem, we did not consider including the correction in the photometric model.

Our paper details how to include a static and rotating flat-field illumination correction in the photometric model for the first time while noting an important degeneracy for polynomials (see Section 2). In Section 3, we use this photometric model to analyse FORS2 observations of standard star fields and derive flat-field correction maps that include both static and rotating illumination corrections. In Section 4, we describe a recipe for the user to follow, which accounts for the static and rotating illumination corrections determined in Section 3, in order to obtain improved FORS2 photometric measurements. We summarize our results in Section 5.

2 MODELLING STATIC AND ROTATING ILLUMINATION CORRECTIONS

In order to derive an illumination correction, the photometric data of a large number of stars observed many times need to be analysed. A fit to such data is relatively easy when a linear model is sufficient to describe the relevant effects. Our goal is to expand the model of Bramich & Freudling (2012) to accommodate static and rotating illumination corrections. A feature of the FORS2 instrument is that it includes two detectors that are simultaneously exposed and they rotate in the focal plane about a common axis. For our discussion below, we use the straight forward generalization to an arbitrary number of detectors. However, we note that our method is limited to the case that the axis of rotation is known a priori. A fit of the rotation centre would lead to a non-linear model and is beyond the scope of our discussion.

We therefore consider a set of N_{data} magnitude measurements m_i (indexed by i) taken from a set of N_{im} images (indexed by r) that are obtained with detectors that are rigidly mounted on a common structure within an instrument. The N_{det} detectors (indexed by k) of the instrument look through the same optical elements and are similar in terms of spectral sensitivity, and each image may come from any one detector. We assume that each observation obtained by the instrument generates N_{det} images at the same epoch, and that the full set of images may include different pointings in the sky. The observations will include measurements of N_{obj} objects (indexed by j). Our adopted indexing implies that the ith magnitude measurement in our photometric data sample belongs to the $j(i)$th object, the $k(i)$th detector and the $r(i)$th image, where the adopted notation for j, k and r reflects the fact that these indices are functions of the index i. However, in the rest of this paper, we use the simplified notation j, k and r for $j(i)$, $k(i)$ and $r(i)$, respectively, in order to avoid confusion in our subscript notation.

Let M_j denote the true instrumental magnitude of the jth object. We also adopt a single reference coordinate system (η, ξ) in the instrument focal plane that applies to all detectors so that each magnitude measurement has associated coordinates (η_i, ξ_i).

Then, we may write our photometric model as

$$\overline{m}_i = M_j + Z + \Delta Z^{\mathrm{det}}_k + \Delta Z^{\mathrm{im}}_r + \Delta F^{\mathrm{stat}}(\eta_i, \xi_i) + \Delta F^{\mathrm{rot}}(\eta'_i, \xi'_i), \tag{1}$$

where $\overline{m}_i$ is the model magnitude for the ith magnitude measurement and Z is the overall system zero-point. By setting $\Delta Z^{\mathrm{det}}_1 = 0$, the quantity $\Delta Z^{\mathrm{det}}_k$ accounts for the sensitivity variation of the kth detector relative to the first detector. By setting $\Delta Z^{\mathrm{im}}_1 = 0$, the quantity $\Delta Z^{\mathrm{det}}_r$ accounts for any variations in the throughput for the light's journey from the top of the atmosphere, through the telescope and instrument, and to the detector surface, for the rth image relative to the first image. The quantity $\Delta F^{\mathrm{stat}}(\eta_i, \xi_i)$ represents the sensitivity variation across the focal plane relative to some arbitrary fiducial coordinates (η_c, ξ_c), where $\Delta F^{\mathrm{stat}}(\eta_c, \xi_c) = 0$, and this term is what we refer to as the static illumination correction. The quantity $\Delta F^{\mathrm{rot}}(\eta'_i, \xi'_i)$ represents the sensitivity variation across the derotated focal plane relative to fiducial coordinates coincident with the centre of rotation (η'_c, ξ'_c), and this term is what we refer to as the rotating illumination correction. For simplicity and without loss of generality, we set $(\eta'_c, \xi'_c) = (\eta_c, \xi_c) = (0, 0)$. Given a rotation angle θ anticlockwise around the origin from the (η, ξ) coordinate system to the (η', ξ') system, we have

$$\eta' = \eta \cos\theta + \xi \sin\theta, \tag{2}$$

$$\xi' = -\eta \sin\theta + \xi \cos\theta. \tag{3}$$

Our photometric model in equation (1) has numerous potential degeneracies. For instance, if none of the M_j are fixed (or known), then the overall zero-point Z becomes degenerate with the M_j because adding a constant C to Z may be offset by subtracting C from all of the M_j. Hence, one M_j for one star should be fixed to an arbitrary value to set the (arbitrary) zero-point of the magnitude scale for the relative calibration. A convenient way to do this is to use the standard magnitude of a known standard star for the value of M_j, which has the advantage that if other M_j values need to be defined rather than fit in order to avoid model degeneracies, then this is possible in a consistent way by using more standard stars. Following on from this, to avoid degeneracies with the detector zero-point offsets $\Delta Z_k^{\mathrm{det}}$, for each detector pair there should be at least one standard star with known M_j observed at least once on both detectors in the set of observations.[1] Degeneracies in the image zero-point offsets ΔZ_r^{im} may be avoided by always ensuring overlapping images and/or the presence of standard star measurements for each image.

In order to constrain the static illumination correction function ΔF^{stat}, multiple observations of the same objects are required with different spatial offsets that cover a grid-like pattern over the two spatial dimensions. Similarly, in order to constrain the rotating illumination correction function ΔF^{rot}, multiple observations of the same objects are required at different 'rotation angles' (for whichever instrument/telescope component rotates relative to the detectors) *and at different distances from the centre of rotation*. This second requirement is important but not so obvious. For example, Hrudková et al. (2010) collected an imaging data set where the photometry reveals a sky-position-angle-dependent systematic error. However, the observations lacked spatial offsets relative to the centre of rotation, and consequently, we found that we could not apply the photometric modelling methodology outlined in this paper to their data. With rotations but no offsets, the annuli of the rotating illumination correction function are constrained, but the relative corrections between annuli remain unconstrained, and therefore, the photometric modelling is a degenerate problem in this case.

Polynomials are a sensible choice of a model for the spatial variation of both the static and rotating illumination corrections since these sensitivity variations are expected to vary smoothly on a relatively large scale (e.g. Paper I). Hence, we adopt[2]

$$\Delta F^{\mathrm{stat}}(\eta, \xi) = \sum_{m=0}^{D_{\mathrm{stat}}} \sum_{n=0}^{D_{\mathrm{stat}}-m} a_{mn}\, \eta^m\, \xi^n, \tag{4}$$

$$\Delta F^{\mathrm{rot}}(\eta', \xi') = \sum_{m=0}^{D_{\mathrm{rot}}} \sum_{n=0}^{D_{\mathrm{rot}}-m} b_{mn}\, \left(\eta'\right)^m \left(\xi'\right)^n, \tag{5}$$

where D_{stat} and D_{rot} are the degrees of the polynomials for the static and rotating illumination corrections, respectively, and a_{mn} and b_{mn} are the polynomial coefficients.

Substituting equations (2) and (3) into equation (5), and then substituting equations (4) and (5) into equation (1), defines the remaining parameters of our photometric model and renders the model as a linear model. However, as written above, some of the model parameters are degenerate because the circularly symmetric component of the illumination correction can be included in either the static or rotating correction. Formally, this is a consequence of the Pythagorean relation:

$$\eta^2 + \xi^2 = \left(\eta'\right)^2 + \left(\xi'\right)^2. \tag{6}$$

[1] In fact, this constraint is somewhat stricter than necessary, but it is a simple constraint that serves our purpose later on.

[2] Although using orthogonal polynomials would help improve the orthogonality of the fitting problem, this choice would not render the fitting problem as fully orthogonal because the dot products that define orthogonality and feature in the normal equations use inverse-variance weights (see later).

To remove this degeneracy without affecting the flexibility of the photometric model, it is sufficient to drop the polynomial terms $(\eta')^{2n}$ for $1 \le n \le \lfloor D_{\mathrm{rot}}/2 \rfloor$.

The fitting of the photometric model to the data follows Bramich & Freudling (2012). First, we write our photometric model using Kronecker delta functions:

$$\overline{m}_i = \left(\sum_{p=1}^{N_{\mathrm{obj}}} \delta_{jp}\, M_p \right) + \left(\sum_{p=1}^{N_{\mathrm{det}}} \delta_{kp}\, \Delta Z_p^{\mathrm{det}} \right) + \left(\sum_{p=1}^{N_{\mathrm{im}}} \delta_{rp}\, \Delta Z_p^{\mathrm{im}} \right) + Z + \Delta F^{\mathrm{stat}}(\eta_i, \xi_i) + \Delta F^{\mathrm{rot}}(\eta_i', \xi_i'), \tag{7}$$

where

$$\delta_{ij} = \begin{cases} 1 & \text{if } i = j \\ 0 & \text{if } i \ne j. \end{cases} \tag{8}$$

Then, with all of the free parameters present in the photometric model, we proceed to minimize the chi-squared:

$$\chi^2 = \sum_{i=1}^{N_{\mathrm{data}}} \left(\frac{m_i - \overline{m}_i}{\sigma_i} \right)^2, \tag{9}$$

where σ_i is the uncertainty on the ith photometric measurement. The chi-squared minimization is achieved by constructing the normal equations for the general linear least-squares problem (Press et al. 2007) and solving them using Cholesky factorization followed by forward and back substitution. Since the size of the matrix for the normal equations may become very large for large problems with data from many objects, we use the property that a submatrix in the normal equations is diagonal to render the problem tractable (see appendix A of Regnault et al. 2009 or section 2.3 of Bramich & Freudling 2012 for details). We also iterate the fitting procedure by rejecting measurements that liemore than $\sqrt{\ln N_{\mathrm{data}}}\sigma_i$ away[3] from the fitted model (and further drop the object observations for which an object now has only a single observation). The iterative fitting is necessary because of the likely presence of variable sources and outlier photometric measurements, and it generally converges within a couple of iterations.

The whole fitting procedure is implemented in the IDL program `fit_photometric_calibration.pro` available as part of the DANIDL[4] library of routines.

3 APPLICATION OF THE PHOTOMETRIC MODEL TO FORS2 OBSERVATIONS OF STANDARD STAR FIELDS

In the following, we apply the photometric model described in Section 2 to a set of standard star fields observed with FORS2 as part of the nightly calibration plan.

3.1 Observations and reductions

We downloaded from the ESO archive[5] FORS2 imaging observations of standard star fields carried out with the *B*, *V*, *R* and *I* ESO filters.[6] We limited our data selection to the time range between 2011 November 1 and 2013 July 7. The starting date coincides with

[3] This is a suitable σ-clip threshold that can be derived by considering the Bayesian information criterion (Schwarz 1978). σ_i is the error on m_i.

[4] http://www.danidl.co.uk

[5] http://archive.eso.org/eso/eso_archive_main.html

[6] They are recorded as b_HIGH+113, v_HIGH+114, R_SPECIAL+76 and I_BESS+77 in the ESO data base, see http://www.eso.org/sci/facilities/paranal/instruments/fors/inst/Filters/.

Table 1. List of the images obtained during photometric nights as part of the FORS2 photometric calibration plan.

NIGHT (yyyy-mm-dd)	FIELD	File name (*B* filter) (FORS2.xxx)	File name (*V* filter) (FORS2.xxx)	File name (*R* filter) (FORS2.xxx)	File name (*I* filter) (FORS2.xxx)
2011-11-07	MarkA	2011-11-07T23:59:08.771	2011-11-08T00:00:06.445	2011-11-08T00:00:59.179	2011-11-08T00:01:46.523
2011-11-07	N6940	2011-11-08T00:09:59.751	2011-11-08T00:10:56.445	2011-11-08T00:11:47.959	2011-11-08T00:12:34.083
2013-05-26	L98	2013-05-26T22:58:23.418	2013-05-26T22:59:19.995	2013-05-26T23:00:11.430	2013-05-26T23:00:57.816
...	...	...	...	...	
2013-05-27	N2818	2013-05-27T22:53:14.066	2013-05-27T22:54:11.412	2013-05-27T22:55:03.838	2013-05-27T22:55:53.354
2013-05-27	L98	2013-05-27T23:01:38.672	2013-05-27T23:02:35.479	2013-05-27T23:03:27.094	2013-05-27T23:04:12.659

Notes. The filenames are defined by the execution date and time (down to the 1 ms level). Here, only images from the FORS2 detector 1 are shown for reasons of clarity. The corresponding image names from detector 2 are obtained by adding 1 ms to the execution time. Files can be downloaded from the ESO archive: http://archive.eso.org/eso/eso_archive_main.html. The number of images per chip are: 271 (Filter *B*), 274 (Filter *V*), 272 (Filter *R*) and 273 (Filter *I*). The entire table is available as supplementary online material.

when the new nightly calibration plan for FORS imaging was put into operations (see Bramich et al. 2012); this plan was indeed defined in order to ensure that the spatial and angular offsets needed to constrain the model for the ΔF^{stat} and ΔF^{rot} illumination correction patterns are performed (see Section 2). The time interval was additionally split into two ranges using the epoch of the UT1-M1 mirror illumination and LADC realignment (2012 May 31–June 11) as a break-point. We will refer to these two time ranges as range A (2011 November 1–2012 May 30) and range B (2012 June 12–2013 July 7). Since such instrument interventions can modify the overall instrumental response and the shape of the illumination patterns that we want to study, we processed the data from the two time ranges independently.

We also imposed the following constraints on the instrument set-up for the data to be analysed: standard resolution collimator, 2 × 2 pixel binning (i.e. spatial scale of 0.25 arcsec per binned pixel), detectors `CCID20-14-5-3` and `CCID20-14-5-6` for chips 1 and 2, respectively. Collimator, binning mode and detector name are indicated by the header keywords `HIERARCH ESO INS COLL NAME`, `HIERARCH ESO DET WIN1 BINX/Y` and `HIERARCH ESO DET CHIP1 ID`, respectively.

According to the calibration plan, at the beginning of each night, two standard star fields from the Stetson catalogue[7] are observed; the first is observed at low airmass and the second at high airmass. If these observations indicate that the night is photometric, more standard star fields are observed during the night to check its photometric stability. Standard star fields are observed at different position angles on the sky, and with different telescope offsets from the nominal field coordinates (from 10 to 60 arcsec).

The data were reduced using the automatic FORS2 ESOREX pipeline version 4.9.23.[8] The pipeline includes automatic identification of the stars, measurement of instrumental magnitudes and cross-checking with the standard star catalogue. The identification of sources and measurement of instrumental magnitudes within the FORS2 pipeline are performed with SEXTRACTOR (Bertin & Arnouts 1996), which evaluates the local sky background and computes 10 arcsec diameter aperture photometry.

One fundamental difference with the standard data reduction cascade is that in our analysis we divided each master flat by its smooth large-scale component. This is created by applying a boxcar smoothing window (200 × 200 pixels) to the master flat frame while masking 2σ outliers (to avoid large variations within few pixels) and regions close to the edges of the illuminated area (to avoid spurious edge effects in the filtering). This new master flat, which contains only the pixel-to-pixel sensitivity variations, is used to calibrate the images. In this way, the large-scale sensitivity variations across the detectors are left unmodified in the photometric data. The aim of this paper is indeed to study these systematic sensitivity variations across the field of view using the photometric data, and to separate them into the contributions of the static (ΔF^{stat}) and rotating (ΔF^{rot}) illumination corrections defined in Section 2.

3.2 Star identification

In our analysis, we use the information from all detected stars in each observed field regardless of whether or not they have catalogued standard magnitudes.

Standard stars are identified by comparing the coordinates of the standard stars in Stetson's reference catalogue with those of all of the detected sources obtained using the frame WCS information. Then, more accurate coordinates and the frame astrometric solution are recomputed by minimizing the offsets in right ascension and declination between the standard stars' coordinates in the image and in the reference catalogue. We refer to the FORS2 pipeline reference manual for more details (see Footnote 8).

Other objects detected in our data are considered to be useful stars if they fulfil the following requirements:

(i) the object is detected in more than three images (to avoid spurious detections);
(ii) the differences between the celestial coordinates of the object as measured in each image must be smaller than 1.2 arcsec on the sky;
(iii) the object must have no other detected source within 3 arcsec;
(iv) the object has a measured magnitude that is brighter than the first quartile of the magnitude histogram in each image (to avoid objects that are too faint).

The above requirements do not apply to standard stars.

Table 1 lists the images obtained during photometric conditions that are used in the fit of the photometric model (see Section 3.4).

3.3 Reference coordinate system

The (η, ξ) reference coordinate system that we used is defined as follows. Let x and y be the pixel coordinates on the calibrated images as reported by the FORS2 data reduction pipeline. The conversion between these coordinates and those of the archival raw images (i.e. not yet processed by the pipeline) are $x = x_{\mathrm{raw}}$, $y = y_{\mathrm{raw}} - 5$, for

[7] See: http://www3.cadc-ccda.hia-iha.nrc-cnrc.gc.ca/community/STETSON/standards/.
[8] The FORS2 data reduction manual and pipeline, and the ESOREX are available at http://www.eso.org/sci/software/pipelines/.

Table 2. Number of standard and other stars detected in all of the observations on photometric nights.

Filter (1)	$N_{\rm obj}^{\rm std}$ (range A) (2)	$N_{\rm data}^{\rm std}$ (range A) (3)	$N_{\rm obj}^{\rm other}$ (range A) (4)	$N_{\rm data}^{\rm other}$ (range A) (5)	$N_{\rm obj}^{\rm std}$ (range B) (6)	$N_{\rm data}^{\rm std}$ (range B) (7)	$N_{\rm obj}^{\rm other}$ (range B) (8)	$N_{\rm data}^{\rm other}$ (range B) (9)
B	1894	4970	1236	5374	2720	23 543	9092	55 885
V	1748	4613	2231	9194	2650	21 564	14 219	94 401
R	1584	4304	2946	12 047	2393	18 910	18 185	112 897
I	1680	4632	2454	10 149	2440	20 579	18 823	116 635

Notes. Column 1: filter identification code: *B* indicates the ESO filter named `b_HIGH+113`, *V* indicates `v_HIGH+114`, *R* indicates `R_SPECIAL+76`and *I* indicates `I_BESS+77`. Column 2: number of (unique) standard stars observed in time range A (2011 November 1–2012 May 30). Column 3: number of instrumental magnitude measurements for the stars in column 2. Column 4: number of (unique) other stars observed in time range A. Column 5: number of instrumental magnitude measurements for the stars in column 4. Columns 6–9: same as columns 2–5, but for time range B (2012 June 12–2013 July 7).

both detectors, due to the removal of pre-/overscan regions during processing.

Consistent with the previous analysis of Paper I, we consider the centre of the illuminated area in the focal plane to be the centre of rotation and the origin of our (η, ξ) reference coordinate system adopted in Section 2. The (x, y) coordinates of this point are

$$x_c^{\rm chip1} = 1022; \quad y_c^{\rm chip1} = 115$$

for chip 1, and

$$x_c^{\rm chip2} = 1022; \quad y_c^{\rm chip2} = 1157$$

for chip 2.

The conversion from the image coordinates (x, y) into the (η, ξ) coordinates is

$$\eta = \frac{x - x_c^{\rm chip1}}{1700}$$
$$\xi = \frac{y - y_c^{\rm chip1}}{1700} \qquad (10)$$

for chip 1, and

$$\eta = \frac{x\cos(\phi) - y\sin(\phi) - x_c^{\rm chip2}}{1700}$$
$$\xi = \frac{x\sin(\phi) + y\cos(\phi) - y_c^{\rm chip2}}{1700} \qquad (11)$$

for chip 2. The number 1700 is an arbitrary but fixed normalization coefficient, which is comparable to the size of the useful field of view ($\sim$1700 × 1700 binned pixels); the quantity ϕ is the offset angle between chips 1 and 2 and it can be read from the header keyword `HIERARCH ESO DET CHIP1 RGAP`. For our data, it is $\phi = 0\overset{\circ}{.}08278$.

The rotator angle θ needed to convert between the coordinate systems (η, ξ) and (η', ξ') (see equations 2 and 3) is computed as the average of the following entries in the image header `HIERARCH ESO ADA ABSROT START` and `HIERARCH ESO ADA ABSROT END`. The maximum difference between the two entries is $0\overset{\circ}{.}77$, which corresponds to a shift of 2.5 arcsec at the border of the FORS2 field of view. The impact on the photometry is negligible, as the rotating illumination correction patterns vary at most by a factor of 1.0001 within 2.5 arcsec.

3.4 Application of the photometric model

In our fit, we used the measured magnitudes m_i of all of the stars that were observed and detected in our data set on nights with stable photometric conditions, as classified by ESO Quality Control.[9] The list of images obtained during photometric conditions is given in Table 1; the number of standard and other stars identified in these images for the considered time ranges is summarized in Table 2.

For each time range, we fitted the photometric model defined in equation (7) to measure: (i) the true instrumental magnitudes M_j of the observed stars, (ii) the values of the coefficients a_{mn} and b_{mn} of the static and rotating illumination corrections defined in equations (4) and (5), respectively. Note that we used the catalogued standard magnitudes to fix the true instrumental magnitude M_j for one standard star in each standard star field since the standard star fields that were observed do not overlap. The true instrumental magnitudes for the remainder of the standard stars, and for the other detected stars, were left as free parameters in the photometric model.

3.5 Results

For each time range, we fitted four models that differ by the degrees of the polynomials representing the static and rotating illumination corrections. Table 3 describes them in detail. Model A represents the photometric model without fitting any illumination corrections, model B represents the model that includes the static illumination correction only (degree 2), model C includes the rotating illumination correction only (degree 2) and model D includes both static and rotating illuminating corrections (both of degree 2).

We repeated the fit many times discarding randomly 40 per cent of the measurements to check the robustness of the fit results, finding consistent static and rotating illumination corrections in all of the random realizations.

Fig. 1 shows the maps of the mean residuals of our models across the focal plane (i.e. in the (η, ξ) coordinate system). If large-scale spatial sensitivity variations are negligible, then, for model A, where no static or rotating illumination correction terms are fitted, there should be no structure in the residual maps above the noise level. However, we do observe such structure (see the top row of panels in Fig. 1) across the focal plane. The inclusion of polynomial surfaces to account for the static and rotating illumination corrections clearly helps to remove these large-scale structures in the residuals and to decrease the χ^2 (see Table 3).

Fig. 2 shows the best-fitting two-dimensional surfaces representing the static and rotating illumination corrections for the different filters and for the two time ranges.

[9] http://www.eso.org/observing/dfo/quality/FORS2/qc/zeropoints/zeropoints.html#stable

Table 3. Description and results for the adopted photometric models.

Model (1)	$D_{\rm stat}$ (2)	$D_{\rm rot}$ (3)	N (4)	D.O.F. (5)	χ^2 (6)	$\tilde{\chi}^2$ (7)	N (8)	D.O.F. (9)	χ^2 (11)	$\tilde{\chi}^2$ (12)
Time range A (2011 November 1–2013 May 13)										
				B filter				*V* filter		
A	0	0	10 344	7177	41 776	5.82	13 807	9792	28 016	2.86
B	0	2	10 344	7173	41 021	5.72	13 807	9788	27 851	2.85
C	2	0	10 344	7172	40 336	5.62	13 807	9787	25 689	2.62
D	2	2	10 344	7168	39 681	5.54	13 807	9783	25 650	2.62
				R filter				*I* filter		
A	0	0	16 351	11 786	23 407	1.99	14 781	10 612	23 488	2.21
B	0	2	16 351	11 782	23 127	1.96	14 781	10 608	23 365	2.20
C	2	0	16 351	11 781	21 841	1.85	14 781	10 607	21 491	2.03
D	2	2	16 351	11 777	21 741	1.85	14 781	10 603	21 460	2.02
Time range B (2012 June 12–2013 July 7)										
				B filter				*V* filter		
A	0	0	79 428	67 418	197 422	2.93	115 965	98 895	326 958	3.31
B	0	2	79 428	67 414	194 185	2.88	115 965	98 891	325 010	3.29
C	2	0	79 428	67 413	179 661	2.67	115 965	98 890	302 577	3.06
D	2	2	79 428	67 409	177 067	2.63	115 965	98 886	300 813	3.04
				R filter				*I* filter		
A	0	0	131 807	111 030	300 992	2.71	137 214	115 752	295 460	2.55
B	0	2	131 807	111 026	299 980	2.70	137 214	115 748	295 050	2.55
C	2	0	131 807	111 025	285 045	2.57	137 214	115 747	277 629	2.40
D	2	2	131 807	111 021	284 093	2.56	137 214	115 743	277 158	2.39

Notes. Column 1: Model label. Columns 2 and 3: degrees of the polynomial surfaces used for the static and rotating illumination corrections. Column 4: number of data points used in the fit, with reference to the *B* and *R* filters. Column 5: model degrees of freedom (D.O.F. = number of data points − number of model parameters), with reference to the *B* and *R* filters. Columns 6 and 7: χ^2 and reduced χ^2 of the model fit, with reference to the *B* and *R* filters. Columns 8–12: Same as columns 4–7, but with reference to the *V* and *I* filters.

The shape of the illumination corrections for the two time ranges are similar for all bands, except for the static correction in the *I* filter. We are still investigating the source of this difference; observations of standard stars after 2013 July will help to monitor the variations of the illumination corrections with time. At the moment, we can exclude causes related to changes in the mechanical components or the set-up of the rotator, because they would have produced a large variation in the rotating patterns between the time ranges for all bands. We can also exclude a degeneracy between the static and rotating patterns, because it would have caused a variation in the *I*-band rotating pattern coupled with the observed variation in the static pattern.

4 IMPROVING FORS2 PHOTOMETRIC MEASUREMENTS

We demonstrated in Section 3.5 that the inclusion of static and rotating illumination correction terms improves the photometric modelling for FORS2 data. The best-fitting coefficients reported in Table 4 can be used to improve the calibration of photometric measurements from any FORS2 observation.

The coefficients associated with time range B have on average smaller errors than those of time range A, as a consequence of the larger numbers of data points available in time range B (see Table 2). However, the different numbers of data points between the two time ranges do not affect the improvement in photometry that can be achieved: indeed, we find later on that the systematic variations in photometric data decrease by very similar amounts for both time ranges when the correction coefficients are applied (see Section 4.3).

In this Section, we test that photometric measurements that are calibrated by the static and rotating illumination corrections represent an improvement with respect to photometric measurements that do not include these corrections.

First, we define 'correct' and 'incorrect' photometric procedures to be those that do and do not, respectively, take into account the static and rotating large-scale spatial sensitivity variations. 'Corrected' magnitudes obtained by a correct photometric procedure will be denoted by $m_i^{\rm C}$. 'Uncorrected' magnitudes obtained by an incorrect photometric procedure will be denoted by $m_i^{\rm U}$.

4.1 'Uncorrected' photometric measurements

'Uncorrected' magnitudes can be obtained, for example, from a data reduction procedure that follows the following steps.

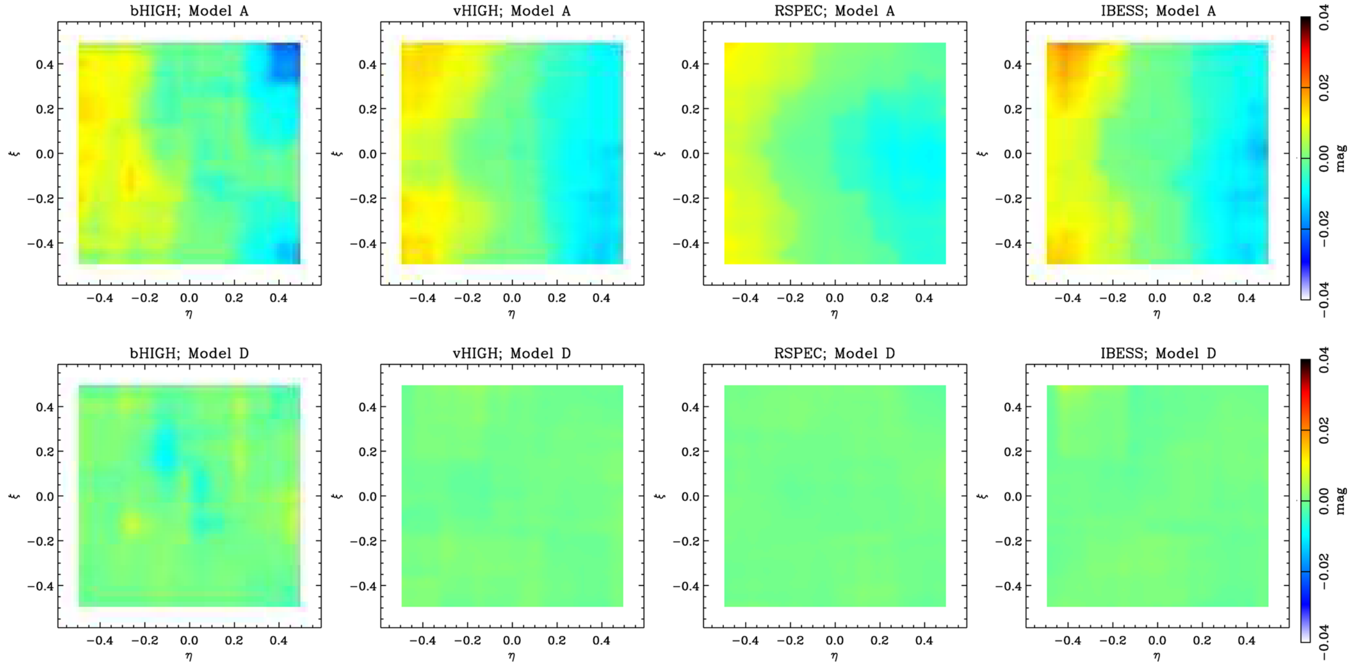
(i) Compute the master bias(es) and master flat(s), for example using FORS_BIAS and FORS_IMG_SKY_FLAT recipes of the FORS2 data reduction pipeline. Use them to calibrate the science image(s).

(ii) Perform the photometry of the stars on the science images, for example using the FORS_ZEROPOINT recipe of the FORS2 data reduction pipeline.

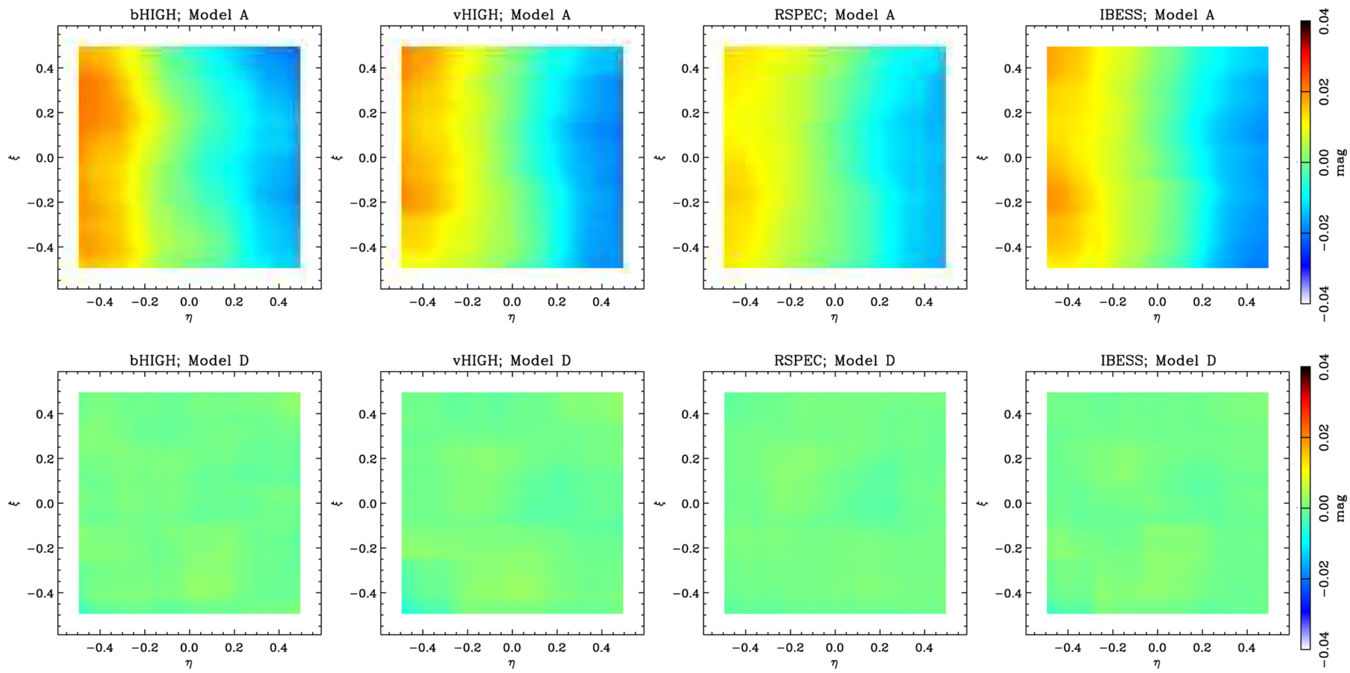
(iii) Using a set of standard star observations on photometric nights, determine the overall zero-point Z, detector zero-point offsets $\Delta Z_k^{\rm det}$ and nightly extinction coefficients λ_n, where the index n refers to the nth night. In other words, fit the following equation to the FORS2 standard star observations:

$$\overline{m}_i = M_j + Z + \Delta Z_k^{\rm det} + \lambda_n X_i, \tag{12}$$

where X_i is the airmass of the ith magnitude measurement. $\overline{m}_i$, M_j, Z and $\Delta Z_k^{\rm det}$ are as in equation (1). This is a standard



(a)



(b)

Figure 1. Two-dimensional maps of mean residuals; panels (a) refer to the data in the time range A (2011 November 1–2012 May 30), whereas panels (b) refer to the time range B (2012 June 12–2013 July 7). Both panels: residuals are computed as the difference between each star magnitude and the model prediction. Upper panels refer to models with no illumination corrections (model A), lower panels refer to the best-fitting models (model D), where both static and rotating illumination corrections have been fitted. Plots in different columns represent the results from different filters. Observations are distributed approximately uniformly across the plotted area.

procedure for zero-point and atmospheric extinction determination for use in the calibration of photometric measurements of science objects.

(iv) Use the best-fitting values of Z, $\Delta Z_k^{\rm det}$ and λ_n to calibrate the instrumental magnitudes of the stars in the science images to obtain the apparent 'uncorrected' magnitudes $m_i^{\rm U}$.

4.2 'Corrected' photometric measurements

A 'correct' photometric data reduction scheme accounts for the sensitivity variations $\Delta F^{\rm stat}$ and $\Delta F^{\rm rot}$. The most efficient way to correct for $\Delta F^{\rm stat}$ and $\Delta F^{\rm rot}$ is to follow the points listed in Section 4.1 above, but using a different master flat frame than the

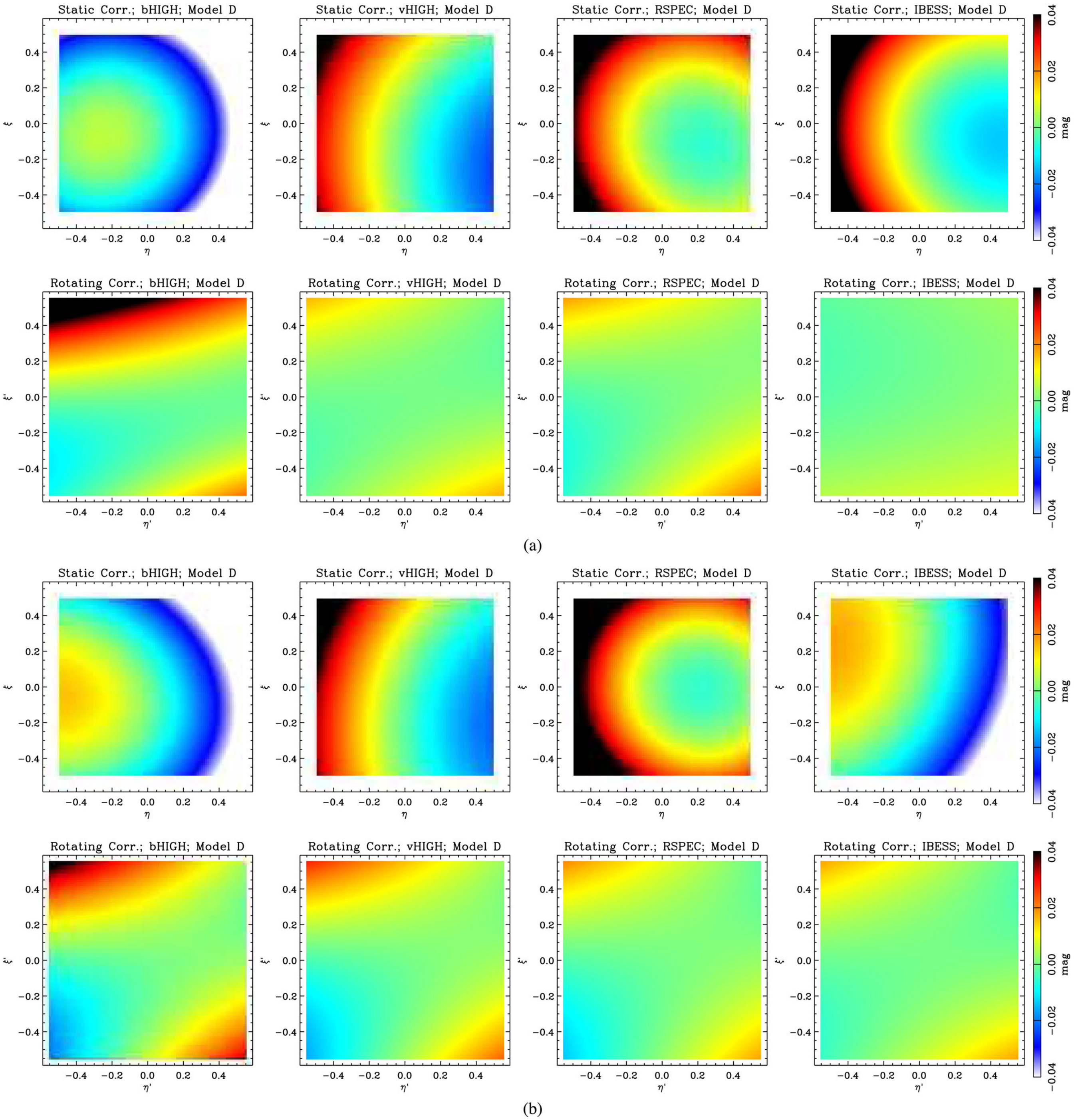


Figure 2. Best-fitting polynomial surfaces (model D) representing the static illumination corrections $\Delta F^{\rm stat}$ (upper panels) and the rotating illumination corrections $\Delta F^{\rm rot}$ (lower panels) for different filters. Illumination correction surfaces in panels (a) refer to time range A, whereas surfaces in panels (b) refer to time range B.

one determined in the first point of the list. This 'improved' master flat frame to be used to calibrate the science images can be obtained as follows.

(i) Compute master bias(es) and master flat(s), for example using the FORS_BIAS and FORS_IMG_SKY_FLAT recipes of the FORS2 data reduction pipeline.

(ii) Remove any large-scale variations from the master flat(s) to leave only the pixel-to-pixel variations. This can be done for example by dividing the master flat by a smoothed version of itself, or by a best-fitting polynomial surface (see Section 3.1).

(iii) Multiply each pixel-to-pixel master flat determined above by the corresponding correcting surface $C(x, y, \theta)$ to obtain the improved master flat. The correcting surface is given by

$$C(x, y, \theta) = 10^{-0.4\,[\Delta F^{\rm stat}(\eta,\xi) + \Delta F^{\rm rot}(\eta',\xi')]}. \qquad (13)$$

$\Delta F^{\rm stat}(\eta, \xi)$ and $\Delta F^{\rm rot}(\eta', \xi')$ are the best-fitting polynomial-surface static and rotating illumination corrections, respectively, whose

Table 4. Best-fitting polynomial coefficients for each time range.

		B filter		*V* filter		*R* filter		**I filter**	
m	n	a_{mn}	b_{mn}	a_{mn}	b_{mn}	a_{mn}	b_{mn}	a_{mn}	b_{mn}
		Time range A: 2011 November 1–2012 May 30							
1	0	-0.043 ± 0.001	-0.001 ± 0.002	-0.054 ± 0.001	0.001 ± 0.001	-0.037 ± 0.001	0.006 ± 0.001	-0.055 ± 0.001	0.004 ± 0.002
0	1	-0.011 ± 0.003	0.031 ± 0.001	0.016 ± 0.002	0.001 ± 0.001	0.015 ± 0.002	0.003 ± 0.001	0.009 ± 0.003	-0.006 ± 0.001
2	0	-0.089 ± 0.008	–	0.023 ± 0.007	–	0.081 ± 0.007	–	0.059 ± 0.008	–
1	1	0.009 ± 0.005	-0.052 ± 0.008	0.011 ± 0.005	-0.027 ± 0.007	0.023 ± 0.004	-0.034 ± 0.006	0.010 ± 0.005	0.001 ± 0.007
0	2	-0.102 ± 0.009	0.077 ± 0.007	0.038 ± 0.007	0.027 ± 0.006	0.085 ± 0.007	0.031 ± 0.005	0.069 ± 0.008	0.013 ± 0.007
		Time range B: 2012 June 12–2013 July 7							
1	0	-0.0570 ± 0.0005	0.0058 ± 0.0006	-0.0574 ± 0.0004	0.0063 ± 0.0005	-0.0450 ± 0.0004	0.0048 ± 0.0005	-0.0544 ± 0.0004	0.0014 ± 0.0005
0	1	-0.014 ± 0.002	0.0154 ± 0.0006	0.016 ± 0.001	0.0109 ± 0.0005	0.001 ± 0.001	0.0065 ± 0.0005	0.023 ± 0.001	0.0013 ± 0.0005
2	0	-0.052 ± 0.009	–	0.032 ± 0.007	–	0.097 ± 0.007	–	-0.045 ± 0.008	–
1	1	-0.013 ± 0.002	-0.075 ± 0.002	-0.005 ± 0.001	-0.052 ± 0.002	0.008 ± 0.001	-0.042 ± 0.002	0.009 ± 0.002	-0.034 ± 0.002
0	2	-0.082 ± 0.009	0.050 ± 0.002	0.033 ± 0.007	0.031 ± 0.002	0.113 ± 0.007	0.019 ± 0.002	-0.038 ± 0.008	0.024 ± 0.002

coefficients are specified in Table 4. We recommend to use the a_{mn} and b_{mn} coefficients determined for time range A if observations are prior to 2012 May 31, and those for time range B if observations are obtained after 2012 June 1.[10] Equations (2), (3), (10) and (11) specify the transformations to convert the detector pixel coordinates (x, y) and rotator angle θ into the coordinates (η, ξ) and (η', ξ') that enable the calculation of $\Delta F^{\rm stat}(\eta, \xi)$ and $\Delta F^{\rm rot}(\eta', \xi')$ via equations (4) and (5). The rotator angle θ is read from the header keywords of the master flat, as specified in Section 3.3. The use of the improved master flats automatically corrects for the large-scale spatial sensitivity variations across the focal plane.

'Corrected' instrumental magnitudes $m_i^{\rm C}$ will be obtained following the steps 2–4 in Section 4.1 and using the improved master flats determined above.

4.3 Improvement in photometry

We now want to test if, and quantify by how much, the application of the static and rotating illumination corrections determined in Section 3.5 to the master flats improves the photometry that is performed on FORS2 images.

We consider now the uncorrected (see Section 4.1) and corrected apparent magnitudes (see Section 4.2) determined for all of the standard stars in our data set (see equation 12) observed at least 10 times under photometric conditions in each filter.

We compare the histograms of the residuals of the uncorrected and corrected magnitudes, $\Delta m_i^{\rm U}$ and $\Delta m_i^{\rm C}$, respectively, in Fig. 3. Residuals are computed as the difference between the apparent magnitude m_i and the median apparent magnitude for the relevant star. In detail, for each standard star we compute

$$\Delta m_i^{\rm U} = m_i^{\rm U} - \langle m_i^{\rm U} \rangle,$$
$$\Delta m_i^{\rm C} = m_i^{\rm C} - \langle m_i^{\rm C} \rangle, \qquad (14)$$

where $\langle\,\rangle$ indicates the median. We find that the use of the corrected magnitudes reduces the scatter in the histograms by $c = \sqrt{\sigma(\Delta m_i^{\rm U})^2 - \sigma(\Delta m_i^{\rm C})^2} = 0.027$, 0.015, 0.008 and 0.019 mag for filters B, V, R and I, respectively, in the time range A. Results for time range B are $c = 0.022$, 0.010, 0.022 and 0.017 mag for filters B, V, R and I, respectively. They represent an improvement of $(1 - 10^{-0.4\,c}) \times 100$ per cent in the photometry. This ranges from 2.5 per cent (filter B) to 0.75 per cent (filter R) for time range A, and from 2.0 per cent (filters B and R) to 0.96 per cent (filter V) for time range B. Standard deviations are calculated removing the 5σ outliers.

We tested that the use of higher polynomial degrees in the parametrization of $\Delta F^{\rm stat}$ and $\Delta F^{\rm rot}$ does not significantly improve the results.

5 SUMMARY

In Paper I, we found a rotating illumination pattern in imaging data from ESO's FORS1 and FORS2 instruments and attributed it to the rotating field rotator unit. The photometric zero-point variations of up to ∼4 per cent across the detectors are big enough to be a concern for precision photometry with these instruments. We also found that this pattern is stable between instrument interventions. The usual strategy of obtaining flat frames that match the position angle of the science observations is cumbersome and suffers from a static illumination pattern that has to be corrected for. On the other hand, the stability of the pattern suggests that it is possible to correct for the rotating illumination pattern and significantly improve the photometric accuracy that can be obtained with these instruments. In this paper, we therefore aimed to derive an analytic correction to the flat frames that can be applied to improve the photometric accuracy.

We used data from the FORS2 nightly standard star observations to derive a photometric model that includes terms for both a static and rotating illumination correction. For this purpose, we generalized the fitting method from Bramich & Freudling (2012). We then derived the corrections to the flat frames, and investigated how the photometric scatter of individual stars improves depending on whether our corrections are used or not. We found that using the analytic corrections, the systematic variations in photometric data taken from 2011 November 1–2012 May 30 decreases by ∼2.5, 1.3, 0.75 and 1.7per cent in the *BVRI* filters, respectively. Similarly, for data taken from 2012 June 12–2013 July 7, the improvements are ∼2.0, 0.96, 2. and 1.6 per cent in the *BVRI* filters, respectively.

The amplitude of the improvements are consistent with the pattern amplitudes found in Paper I for FORS2. We therefore suggest that flat frames for the FORS2 instrument should be corrected by the applicable analytic expressions of equations (4) and (5), whose

[10] As consistency check, we tested that if coefficients are applied to observations of the wrong time range, the systematic variations in photometric data can increase up to ∼1.7 per cent, as measured following the prescriptions detailed in Section 4.3.

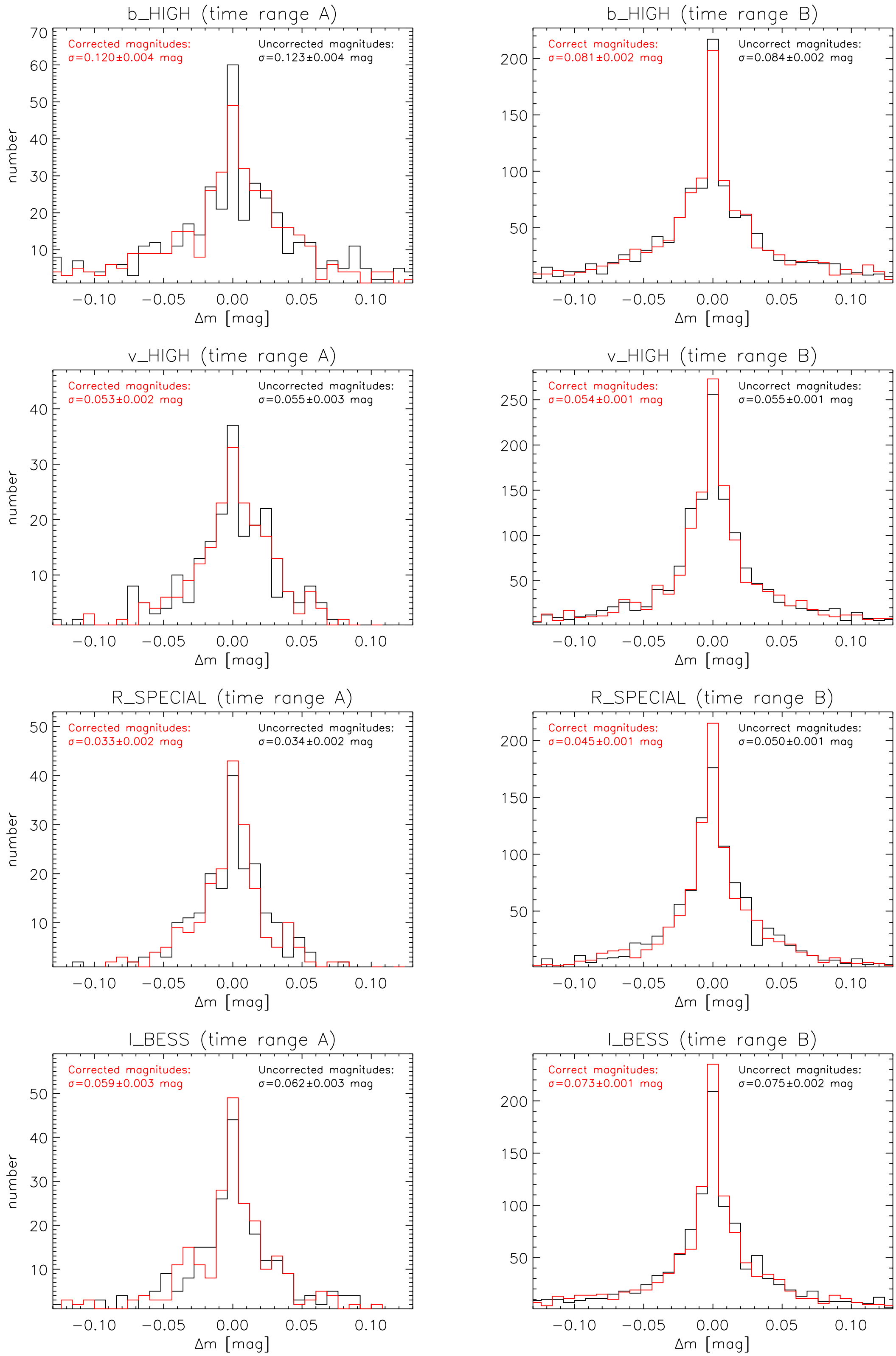


Figure 3. Comparison between the magnitude scatter of uncorrected magnitudes (black) and corrected magnitudes (red). Histograms include only standard stars observed at least 10 times in our data set, and with the standard deviation of $\Delta m_i^{\mathrm{U,C}}$ less than 0.3 mag.

coefficients are given in Table 4, before they are applied to science data.

ACKNOWLEDGEMENTS

LC acknowledges funding from the European Community Seventh Framework Programme (FP7/2007-2013/) under grant agreement no. 229517. This research has benefited from the use of the following IDL libraries: DANIDL (http://www.danidl.co.uk) and MARKWARDT (http://cow.physics.wisc.edu/~craigm/idl/idl.html). This research is based on data obtained from the ESO Science Archive Facility under request ID: LCOCCATO-77441.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Table 1. List of the images obtained during photometric nights as part of the FORS2 photometric calibration plan (http://mnras.oxfordjournals.org/lookup/suppl/doi:10.1093/mnras/stt2272/-/DC1).

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Table 1: List of the images obtained during photometric nights as part of the FORS2 photometric calibration plan.

NIGHT (yyyy-mm-dd)	FIELD	File name (*B*-filter) (FORS2.xxx)	File name (*V*-filter) (FORS2.xxx)	File name (*R*-filter) (FORS2.xxx)	File name (*I*-filter) (FORS2.xxx)
2011-11-07	MarkA	2011-11-07T23:59:08.771	2011-11-08T00:00:06.445	2011-11-08T00:00:59.179	2011-11-08T00:01:46.523
2011-11-07	N6940	2011-11-08T00:09:59.751	2011-11-08T00:10:56.445	2011-11-08T00:11:47.959	2011-11-08T00:12:34.083
2011-11-07	PG0231	–	–	2011-11-08T03:51:20.551	2011-11-08T03:52:06.794
2011-11-21	T_Phe	2011-11-21T23:54:34.442	2011-11-21T23:55:33.357	2011-11-21T23:56:25.431	2011-11-21T23:57:12.034
2011-11-21	PG0231	2011-11-22T00:01:31.814	2011-11-22T00:02:29.408	2011-11-22T00:03:21.012	2011-11-22T00:04:07.185
2011-11-21	N2298	2011-11-22T05:29:38.410	2011-11-22T05:30:36.154	2011-11-22T05:31:28.428	2011-11-22T05:32:15.101
2011-11-23	T_Phe	2011-11-24T02:48:58.442	2011-11-24T02:49:56.677	2011-11-24T02:50:48.790	2011-11-24T02:51:34.924
2011-12-01	L95	2011-12-02T03:15:25.425	2011-12-02T03:16:22.810	2011-12-02T03:17:14.523	2011-12-02T03:18:00.877
2011-12-01	L98	2011-12-02T03:23:06.041	2011-12-02T03:24:03.195	2011-12-02T03:24:54.609	2011-12-02T03:25:40.893
2011-12-29	T_Phe	2011-12-30T00:28:54.179	2011-12-30T00:29:52.444	2011-12-30T00:30:44.908	2011-12-30T00:31:30.972
2011-12-29	E3	2011-12-30T00:37:31.221	2011-12-30T00:38:28.485	2011-12-30T00:39:20.360	2011-12-30T00:40:06.543
2012-01-11	N2298	2012-01-12T04:59:37.902	2012-01-12T05:00:35.916	2012-01-12T05:01:28.129	2012-01-12T05:02:14.233
2012-01-11	L95	2012-01-12T05:21:10.742	2012-01-12T05:22:07.876	2012-01-12T05:22:59.409	2012-01-12T05:23:44.953
2012-01-11	N5139	2012-01-12T07:53:30.320	2012-01-12T07:54:30.135	2012-01-12T07:55:22.319	2012-01-12T07:56:10.662
2012-01-13	L95	2012-01-14T00:35:12.033	2012-01-14T00:36:09.168	2012-01-14T00:37:01.512	2012-01-14T00:37:47.476
2012-01-13	N2298	2012-01-14T00:46:20.345	2012-01-14T00:47:18.880	2012-01-14T00:48:11.324	2012-01-14T00:48:58.878
2012-01-13	L95	2012-01-14T01:26:03.550	2012-01-14T01:27:01.244	2012-01-14T01:27:53.569	2012-01-14T01:28:39.532
2012-01-16	L95	2012-01-17T00:45:25.051	2012-01-17T00:46:21.405	2012-01-17T00:47:12.930	2012-01-17T00:47:59.193
2012-01-16	Ru149	2012-01-17T00:53:16.698	2012-01-17T00:54:13.713	2012-01-17T00:55:04.686	2012-01-17T00:55:50.309
2012-01-16	LeoI	2012-01-17T08:08:17.034	2012-01-17T08:09:14.629	2012-01-17T08:10:06.673	2012-01-17T08:10:52.636
2012-01-16	L101	2012-01-17T08:51:22.091	2012-01-17T08:52:20.935	2012-01-17T08:53:14.429	2012-01-17T08:54:01.103
2012-01-18	L95	2012-01-19T00:31:55.149	2012-01-19T00:32:51.654	2012-01-19T00:33:43.158	2012-01-19T00:34:28.611
2012-01-18	Ru149	2012-01-19T00:38:28.170	2012-01-19T00:39:25.604	2012-01-19T00:40:16.918	2012-01-19T00:41:02.212
2012-01-18	N2298	2012-01-19T07:14:08.051	2012-01-19T07:15:05.665	2012-01-19T07:15:57.149	2012-01-19T07:16:43.382
2012-01-19	L95	2012-01-20T00:32:14.409	2012-01-20T00:33:11.393	–	2012-01-20T00:34:48.621
2012-01-19	N2298	2012-01-20T05:49:22.904	–	–	–
2012-01-22	L95	2012-01-23T00:31:16.761	2012-01-23T00:32:12.795	2012-01-23T00:33:03.769	2012-01-23T00:33:49.572
2012-01-22	Ru149	2012-01-23T00:38:25.763	2012-01-23T00:39:23.118	2012-01-23T00:40:14.281	2012-01-23T00:40:59.655
2012-01-22	LeoI	2012-01-23T08:36:29.417	2012-01-23T08:37:25.992	2012-01-23T08:38:17.545	2012-01-23T08:39:03.749
2012-01-23	L95	2012-01-24T00:19:46.592	2012-01-24T00:20:42.986	2012-01-24T00:21:34.720	2012-01-24T00:22:20.183
2012-01-23	Ru149	2012-01-24T00:47:29.869	2012-01-24T00:48:41.514	2012-01-24T00:49:44.739	2012-01-24T00:50:42.763
2012-01-23	Ru149	2012-01-24T00:52:19.941	2012-01-24T00:53:24.245	2012-01-24T00:54:27.441	2012-01-24T00:55:16.404
2012-01-23	N2298	2012-01-24T05:05:30.650	2012-01-24T05:06:28.274	2012-01-24T05:07:20.318	2012-01-24T05:08:06.662
2012-01-23	LeoI	2012-01-24T08:57:47.595	2012-01-24T08:58:44.569	2012-01-24T08:59:35.593	2012-01-24T09:00:21.197
2012-01-24	L95	2012-01-25T00:20:08.189	2012-01-25T00:21:04.723	2012-01-25T00:21:56.217	2012-01-25T00:22:42.070
2012-01-24	Ru149	2012-01-25T00:44:56.535	2012-01-25T00:45:56.030	2012-01-25T00:46:54.054	2012-01-25T00:47:41.748
2012-01-24	N2298	2012-01-25T06:19:24.537	2012-01-25T06:20:22.231	2012-01-25T06:21:15.265	2012-01-25T06:22:01.819
2012-01-24	LeoI	2012-01-25T08:54:39.088	2012-01-25T08:55:36.983	2012-01-25T08:56:28.686	2012-01-25T08:57:14.590
2012-01-27	N2818	2012-01-28T00:59:38.545	2012-01-28T01:00:36.219	2012-01-28T01:01:27.923	2012-01-28T01:02:13.517
2012-01-27	L95	2012-01-28T01:05:57.963	2012-01-28T01:06:56.187	2012-01-28T01:07:48.832	2012-01-28T01:08:35.555
2012-01-27	N2298	2012-01-28T04:06:06.952	2012-01-28T04:07:05.847	2012-01-28T04:07:58.111	2012-01-28T04:08:44.294
2012-01-31	N2298	2012-02-01T01:52:04.408	2012-02-01T01:53:01.852	2012-02-01T01:53:54.606	2012-02-01T01:54:40.920
2012-01-31	N2818	2012-02-01T02:07:33.518	2012-02-01T02:08:31.902	2012-02-01T02:09:25.276	2012-02-01T02:10:12.780
2012-01-31	N2818	2012-02-01T03:39:16.588	2012-02-01T03:40:15.602	2012-02-01T03:41:07.377	2012-02-01T03:41:53.990
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2012-01-31	I4499	2012-02-01T08:25:50.690	2012-02-01T08:26:47.894	2012-02-01T08:27:39.248	2012-02-01T08:28:25.482
2012-02-22	N2298	2012-02-23T00:20:33.355	2012-02-23T00:21:33.001	2012-02-23T00:22:25.147	2012-02-23T00:23:11.432
2012-02-22	N2420	2012-02-23T00:26:50.027	2012-02-23T00:27:47.443	2012-02-23T00:28:38.359	2012-02-23T00:29:23.904
2012-02-22	Ru149	2012-02-23T04:35:51.680	2012-02-23T04:36:50.616	2012-02-23T04:37:41.612	2012-02-23T04:38:28.007
2012-02-22	E7	2012-02-23T08:33:31.416	2012-02-23T08:34:27.752	2012-02-23T08:35:19.667	2012-02-23T08:36:05.022
2012-03-03	N2298	2012-03-04T00:31:10.106	2012-03-04T00:32:09.943	2012-03-04T00:33:03.038	2012-03-04T00:33:50.964
2012-06-15	E5	2012-06-15T22:49:41.739	2012-06-15T22:50:41.624	2012-06-15T22:51:36.009	2012-06-15T22:52:25.053
2012-06-15	M4	2012-06-15T22:57:48.980	2012-06-15T22:58:48.466	2012-06-15T22:59:42.510	2012-06-15T23:00:30.314
2012-06-15	M4	2012-06-16T06:48:20.959	2012-06-16T06:51:00.832	2012-06-16T06:51:54.617	2012-06-16T06:52:43.051
2012-06-15	MarkA	2012-06-16T10:24:33.063	2012-06-16T10:25:33.708	2012-06-16T10:26:28.882	2012-06-16T10:27:19.397
2012-06-23	E5	2012-06-23T22:47:45.852	2012-06-23T22:48:44.597	2012-06-23T22:49:39.008	2012-06-23T22:50:27.256
2012-06-23	PG2213	2012-06-24T08:54:04.173	2012-06-24T08:55:04.358	2012-06-24T08:55:58.312	2012-06-24T08:56:46.187
2012-06-23	N6940	2012-06-24T09:01:14.448	2012-06-24T09:02:13.694	2012-06-24T09:03:07.658	2012-06-24T09:03:56.352
2012-06-23	MarkA	2012-06-24T10:10:28.690	2012-06-24T10:11:28.925	2012-06-24T10:12:22.940	2012-06-24T10:13:10.724
2012-06-30	E5	2012-06-30T23:30:42.323	2012-06-30T23:31:42.878	–	–
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2012-06-30	N6940	2012-07-01T05:04:01.769	2012-07-01T05:05:01.725	2012-07-01T05:05:55.820	2012-07-01T05:06:43.754

Tab. A1: (continue).

2012-06-30	MarkA	2012-07-01T08:12:24.896	2012-07-01T08:13:25.532	2012-07-01T08:14:20.507	2012-07-01T08:15:10.331
2012-06-30	L92	2012-07-01T08:26:16.368	2012-07-01T08:27:15.843	2012-07-01T08:28:09.847	2012-07-01T08:28:58.172
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2012-07-03	N5139	2012-07-03T22:50:43.488	2012-07-03T22:51:42.983	2012-07-03T22:52:37.498	2012-07-03T22:53:25.611
2012-07-03	L101	2012-07-03T22:56:53.039	2012-07-03T22:57:52.664	2012-07-03T22:58:46.039	2012-07-03T22:59:34.023
2012-08-18	E7	2012-08-18T23:11:12.316	2012-08-18T23:12:13.220	2012-08-18T23:13:07.824	2012-08-18T23:14:01.028
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2012-08-18	PG2213	2012-08-19T05:37:53.828	2012-08-19T05:38:51.552	2012-08-19T05:39:43.376	2012-08-19T05:40:30.090
2012-08-18	PG2213	2012-08-19T06:15:07.326	2012-08-19T06:16:05.491	2012-08-19T06:16:57.784	2012-08-19T06:17:44.497
2012-08-18	N2298	2012-08-19T10:01:12.931	2012-08-19T10:02:10.266	2012-08-19T10:03:01.499	2012-08-19T10:03:47.592
2012-08-20	E7	2012-08-20T23:16:31.628	2012-08-20T23:17:28.583	2012-08-20T23:18:21.027	2012-08-20T23:19:07.221
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2012-08-20	N2298	2012-08-21T09:41:59.072	2012-08-21T09:42:56.807	2012-08-21T09:43:48.221	2012-08-21T09:44:34.004
2012-08-21	E7	2012-08-21T23:15:15.667	2012-08-21T23:16:13.891	2012-08-21T23:17:05.225	2012-08-21T23:17:51.499
2012-08-21	E5	2012-08-21T23:29:20.571	2012-08-21T23:30:16.925	2012-08-21T23:31:08.289	2012-08-21T23:31:54.212
2012-08-21	L110	2012-08-22T05:09:25.499	2012-08-22T05:10:22.543	2012-08-22T05:11:14.106	2012-08-22T05:11:59.430
2012-08-21	N2298	2012-08-22T09:47:13.700	2012-08-22T09:48:11.354	2012-08-22T09:49:02.017	2012-08-22T09:49:47.650
2012-08-22	E7	2012-08-22T23:20:24.211	2012-08-22T23:21:25.345	2012-08-22T23:22:20.849	2012-08-22T23:23:12.662
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2012-08-22	T_Phe	2012-08-23T04:35:47.357	2012-08-23T04:36:48.182	2012-08-23T04:37:40.695	2012-08-23T04:38:27.379
2012-08-23	E7	2012-08-23T23:07:32.444	2012-08-23T23:08:30.117	2012-08-23T23:09:21.701	2012-08-23T23:10:07.754
2012-08-23	E5	2012-08-23T23:16:56.982	2012-08-23T23:17:54.506	2012-08-23T23:18:45.730	2012-08-23T23:19:31.353
2012-08-24	E7	2012-08-24T23:06:56.080	2012-08-24T23:07:53.744	2012-08-24T23:08:45.727	2012-08-24T23:09:31.271
2012-08-24	E5	2012-08-24T23:16:52.372	2012-08-24T23:17:49.686	2012-08-24T23:18:41.200	2012-08-24T23:19:26.983
2012-08-24	L110	2012-08-25T05:38:20.856	2012-08-25T05:39:17.980	2012-08-25T05:40:09.524	2012-08-25T05:40:55.018
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2012-08-26	N2298	2012-08-27T09:40:03.038	2012-08-27T09:40:59.902	2012-08-27T09:41:51.146	2012-08-27T09:42:36.700
2012-08-28	E7	2012-08-28T23:13:12.597	2012-08-28T23:14:10.222	2012-08-28T23:15:01.876	2012-08-28T23:15:48.119
2012-08-28	N5139	2012-08-28T23:19:33.896	2012-08-28T23:20:31.461	2012-08-28T23:21:23.174	2012-08-28T23:22:09.639
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2012-09-07	N2298	2012-09-08T09:39:07.269	2012-09-08T09:40:07.193	2012-09-08T09:40:59.967	2012-09-08T09:41:47.490
2012-09-09	MarkA	2012-09-10T03:27:26.592	2012-09-10T03:28:24.637	2012-09-10T03:29:18.031	2012-09-10T03:30:05.494
2012-09-09	L92	2012-09-10T09:44:00.956	2012-09-10T09:44:58.401	2012-09-10T09:45:50.904	2012-09-10T09:46:37.658
2012-09-12	E7	2012-09-12T23:24:48.260	2012-09-12T23:25:45.914	2012-09-12T23:26:36.978	2012-09-12T23:27:23.672
2012-09-12	N5139	2012-09-12T23:31:07.080	2012-09-12T23:32:04.815	2012-09-12T23:32:56.690	2012-09-12T23:33:43.063
2012-09-12	MarkA	2012-09-13T05:14:10.985	2012-09-13T05:15:08.560	2012-09-13T05:16:00.204	2012-09-13T05:16:46.228
2012-09-13	E7	2012-09-13T23:29:00.110	2012-09-13T23:29:58.645	2012-09-13T23:30:49.519	2012-09-13T23:31:35.312
2012-09-13	MarkA	2012-09-14T03:38:58.613	2012-09-14T03:39:57.158	2012-09-14T03:40:49.072	2012-09-14T03:41:35.485
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2012-09-23	MarkA	2012-09-24T01:42:00.729	2012-09-24T01:42:58.714	2012-09-24T01:43:50.988	2012-09-24T01:44:37.302
2012-09-23	N6940	2012-09-24T01:51:51.821	2012-09-24T01:52:49.106	2012-09-24T01:53:40.831	2012-09-24T01:54:27.174
2012-09-23	N6940	2012-09-24T01:56:17.544	2012-09-24T01:57:13.189	2012-09-24T01:58:02.483	2012-09-24T01:58:46.897
2012-09-29	E7	2012-09-30T00:38:48.763	2012-09-30T00:39:47.438	2012-09-30T00:40:39.543	2012-09-30T00:41:25.777
2012-09-29	N6940	2012-09-30T00:45:23.839	2012-09-30T00:46:21.044	2012-09-30T00:47:12.519	2012-09-30T00:47:58.283
2012-09-29	L98	2012-09-30T08:49:32.983	2012-09-30T08:50:31.468	2012-09-30T08:51:23.533	2012-09-30T08:52:10.997
2012-09-29	N2420	2012-09-30T09:00:14.529	2012-09-30T09:01:11.174	2012-09-30T09:02:11.149	2012-09-30T09:02:57.203
2012-10-01	MarkA	2012-10-02T03:10:16.368	2012-10-02T03:11:16.943	2012-10-02T03:12:10.288	2012-10-02T03:12:58.003
2012-10-01	PG2213	2012-10-02T03:18:02.759	2012-10-02T03:19:00.754	2012-10-02T03:19:53.219	2012-10-02T03:20:40.612
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2012-10-01	T_Phe	2012-10-02T05:02:16.853	2012-10-02T05:03:14.908	2012-10-02T05:04:07.092	2012-10-02T05:04:53.417
2012-10-01	T_Phe	2012-10-02T05:05:52.792	–	–	–
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2012-10-05	M4	2012-10-06T00:29:51.153	2012-10-06T00:30:51.929	2012-10-06T00:31:46.113	2012-10-06T00:32:33.357
2012-10-05	PG2213	2012-10-06T05:11:23.869	2012-10-06T05:12:23.664	2012-10-06T05:13:17.278	2012-10-06T05:14:05.392
2012-10-05	L95	2012-10-06T06:38:12.087	2012-10-06T06:39:12.101	2012-10-06T06:40:05.856	2012-10-06T06:40:53.979
2012-10-06	M4	2012-10-06T23:40:43.016	2012-10-06T23:41:42.791	2012-10-06T23:42:36.565	2012-10-06T23:43:25.119
2012-10-06	T_Phe	2012-10-06T23:52:50.745	2012-10-06T23:53:55.351	2012-10-06T23:54:51.835	2012-10-06T23:55:41.890
2012-10-06	PG2213	2012-10-07T04:11:58.711	2012-10-07T04:12:59.686	2012-10-07T04:13:54.830	2012-10-07T04:14:43.824
2012-10-06	E3	2012-10-07T09:19:37.114	2012-10-07T09:20:37.188	2012-10-07T09:21:31.443	2012-10-07T09:22:20.647
2012-10-07	MarkA	2012-10-07T23:30:12.587	2012-10-07T23:31:12.642	2012-10-07T23:32:06.596	2012-10-07T23:32:54.630
2012-10-07	PG1633	2012-10-07T23:40:03.745	2012-10-07T23:41:03.100	2012-10-07T23:41:57.135	2012-10-07T23:42:45.119

Tab. A1: (continue).

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2012-10-09	MarkA	2012-10-09T23:30:44.029	2012-10-09T23:31:45.544	2012-10-09T23:32:39.509	2012-10-09T23:33:28.303
2012-10-09	PG1633	2012-10-09T23:40:43.640	2012-10-09T23:41:43.285	2012-10-09T23:42:37.379	2012-10-09T23:43:25.834
2012-10-09	PG2213	2012-10-10T04:29:07.922	2012-10-10T04:30:08.016	2012-10-10T04:31:01.931	2012-10-10T04:31:49.425
2012-10-09	Ru149	2012-10-10T09:32:34.528	2012-10-10T09:33:35.582	2012-10-10T09:34:30.067	2012-10-10T09:35:19.421
2012-10-10	MarkA	2012-10-10T23:24:41.464	2012-10-10T23:25:41.899	2012-10-10T23:26:37.124	2012-10-10T23:27:25.808
2012-10-10	PG1633	2012-10-10T23:32:50.835	2012-10-10T23:33:51.010	2012-10-10T23:34:44.994	2012-10-10T23:35:33.748
2012-10-10	PG0231	2012-10-11T05:45:07.768	2012-10-11T05:46:06.853	2012-10-11T05:47:01.047	2012-10-11T05:47:49.061
2012-10-10	N2298	2012-10-11T09:08:33.054	2012-10-11T09:09:33.690	2012-10-11T09:10:27.894	2012-10-11T09:11:17.078
2012-10-12	MarkA	2012-10-12T23:27:21.400	2012-10-12T23:28:21.795	2012-10-12T23:29:16.469	2012-10-12T23:30:05.164
2012-10-12	PG1633	2012-10-12T23:39:35.042	2012-10-12T23:40:34.477	2012-10-12T23:41:28.481	2012-10-12T23:42:16.315
2012-10-12	PG2213	2012-10-13T03:36:38.696	2012-10-13T03:37:39.421	2012-10-13T03:38:34.526	2012-10-13T03:39:23.830
2012-10-12	N2298	2012-10-13T07:21:11.395	2012-10-13T07:22:12.571	2012-10-13T07:23:07.705	2012-10-13T07:23:56.719
2012-10-14	MarkA	2012-10-14T23:28:41.392	2012-10-14T23:29:42.128	2012-10-14T23:30:37.222	2012-10-14T23:31:25.206
2012-10-14	PG1633	2012-10-14T23:36:31.762	2012-10-14T23:37:31.207	2012-10-14T23:38:24.721	2012-10-14T23:39:12.596
2012-10-14	PG2213	2012-10-15T04:03:28.034	2012-10-15T04:04:28.449	2012-10-15T04:05:22.434	2012-10-15T04:06:11.208
2012-10-14	Ru149	2012-10-15T09:24:14.038	2012-10-15T09:25:15.282	2012-10-15T09:26:09.307	2012-10-15T09:26:58.631
2012-10-15	MarkA	2012-10-16T00:02:09.259	2012-10-16T00:03:10.534	2012-10-16T00:04:04.878	2012-10-16T00:04:52.713
2012-10-15	M4	2012-10-16T00:13:29.308	2012-10-16T00:14:34.004	2012-10-16T00:15:28.619	2012-10-16T00:16:16.563
2012-10-15	L95	2012-10-16T04:43:46.788	2012-10-16T04:44:47.323	2012-10-16T04:45:41.407	2012-10-16T04:46:30.662
2012-10-15	N2818	2012-10-16T08:09:45.079	2012-10-16T08:10:45.104	2012-10-16T08:11:38.639	2012-10-16T08:12:26.423
2012-10-20	L92	2012-10-21T02:51:50.682	2012-10-21T02:52:50.157	2012-10-21T02:53:43.932	2012-10-21T02:54:32.656
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2012-10-20	Ru149	2012-10-21T08:12:42.569	2012-10-21T08:13:43.514	2012-10-21T08:14:39.268	2012-10-21T08:15:27.982
2012-10-22	L95	2012-10-23T04:33:47.062	2012-10-23T04:34:49.567	2012-10-23T04:35:44.561	2012-10-23T04:36:33.785
2012-10-22	E3	2012-10-23T04:41:14.798	2012-10-23T04:42:15.123	2012-10-23T04:43:09.327	2012-10-23T04:43:59.142
2012-10-22	N2818	2012-10-23T08:50:39.479	2012-10-23T08:51:40.794	2012-10-23T08:52:36.768	2012-10-23T08:53:26.192
2012-10-31	MarkA	2012-11-01T00:08:34.246	2012-11-01T00:09:36.491	2012-11-01T00:10:28.326	2012-11-01T00:11:14.470
2012-10-31	N6940	2012-11-01T00:15:17.071	2012-11-01T00:16:14.176	2012-11-01T00:17:05.630	2012-11-01T00:17:51.125
2012-10-31	L95	2012-11-01T05:07:20.400	2012-11-01T05:08:18.734	2012-11-01T05:09:09.759	2012-11-01T05:09:55.682
2012-11-03	MarkA	2012-11-03T23:54:27.393	2012-11-03T23:55:24.938	2012-11-03T23:56:17.283	2012-11-03T23:57:03.947
2012-11-03	N6940	2012-11-04T00:01:27.101	2012-11-04T00:02:24.406	2012-11-04T00:03:15.250	2012-11-04T00:04:01.145
2012-11-07	MarkA	2012-11-08T00:05:52.138	2012-11-08T00:06:49.782	2012-11-08T00:07:41.707	2012-11-08T00:08:28.081
2012-11-07	N6940	2012-11-08T00:14:36.905	2012-11-08T00:15:33.359	2012-11-08T00:16:23.924	2012-11-08T00:17:09.508
2012-11-07	E3	2012-11-08T04:32:04.172	2012-11-08T04:33:01.767	2012-11-08T04:33:52.652	2012-11-08T04:34:38.456
2012-11-08	MarkA	2012-11-09T01:50:02.955	2012-11-09T01:50:59.880	2012-11-09T01:51:50.164	2012-11-09T01:52:35.898
2012-11-08	T_Phe	2012-11-09T02:02:42.547	2012-11-09T02:03:42.672	2012-11-09T02:04:39.137	2012-11-09T02:05:29.351
2012-11-08	E3	2012-11-09T04:38:35.443	2012-11-09T04:39:32.058	2012-11-09T04:40:23.443	2012-11-09T04:41:08.836
2012-11-09	MarkA	2012-11-10T01:26:42.428	2012-11-10T01:27:39.523	2012-11-10T01:28:30.377	2012-11-10T01:29:16.181
2012-11-09	T_Phe	2012-11-10T01:34:09.336	2012-11-10T01:35:10.421	2012-11-10T01:36:05.725	2012-11-10T01:37:01.419
2012-12-08	L92	2012-12-09T00:06:31.997	2012-12-09T00:07:29.472	2012-12-09T00:08:20.635	2012-12-09T00:09:06.149
2012-12-08	PG2213	2012-12-09T00:42:51.045	2012-12-09T00:43:48.410	2012-12-09T00:44:39.624	2012-12-09T00:45:24.738
2012-12-08	PG2213	2012-12-09T00:47:57.790	2012-12-09T00:48:54.924	2012-12-09T00:49:46.238	2012-12-09T00:50:33.302
2012-12-08	N2298	2012-12-09T04:07:41.094	2012-12-09T04:08:39.238	2012-12-09T04:09:31.273	2012-12-09T04:10:17.397
2012-12-09	PG0231	–	2012-12-10T00:15:21.796	2012-12-10T00:16:14.629	2012-12-10T00:17:00.184
2012-12-09	L95	2012-12-10T00:47:35.762	2012-12-10T00:48:32.496	2012-12-10T00:49:24.921	2012-12-10T00:50:11.554
2012-12-09	E3	2012-12-10T02:17:13.951	2012-12-10T02:18:11.056	2012-12-10T02:19:01.980	2012-12-10T02:19:47.753
2012-12-09	N2298	2012-12-10T08:11:22.014	2012-12-10T08:12:19.629	2012-12-10T08:13:11.773	2012-12-10T08:14:00.087
2012-12-12	L92	2012-12-13T00:51:47.717	2012-12-13T00:52:45.471	2012-12-13T00:53:36.835	2012-12-13T00:54:23.199
2012-12-12	E3	2012-12-13T01:02:04.155	2012-12-13T01:03:01.160	2012-12-13T01:03:52.134	2012-12-13T01:04:37.348
2012-12-12	L95	2012-12-13T03:38:08.916	2012-12-13T03:39:05.860	2012-12-13T03:39:57.584	2012-12-13T03:40:44.228
2012-12-12	N2298	2012-12-13T07:29:16.763	2012-12-13T07:30:14.197	2012-12-13T07:31:05.831	2012-12-13T07:31:51.874
2012-12-13	L92	2012-12-14T00:14:33.080	2012-12-14T00:15:30.715	2012-12-14T00:16:21.679	2012-12-14T00:17:08.572
2012-12-13	MarkA	2012-12-14T00:29:14.450	2012-12-14T00:30:11.255	2012-12-14T00:31:02.819	2012-12-14T00:31:48.123
2012-12-13	Ru149	2012-12-14T04:41:41.952	2012-12-14T04:42:39.806	2012-12-14T04:43:32.080	2012-12-14T04:44:18.824
2012-12-14	L92	2012-12-15T00:22:01.616	2012-12-15T00:22:58.860	2012-12-15T00:23:50.464	2012-12-15T00:24:36.508
2012-12-14	L92	2012-12-15T00:25:30.182	2012-12-15T00:26:28.277	2012-12-15T00:27:20.240	2012-12-15T00:28:06.464
2012-12-14	E3	2012-12-15T00:51:18.231	2012-12-15T00:52:15.805	2012-12-15T00:53:07.259	2012-12-15T00:53:53.652
2012-12-15	L92	2012-12-16T00:15:41.145	2012-12-16T00:16:37.869	2012-12-16T00:17:29.873	2012-12-16T00:18:15.727
2012-12-15	E3	2012-12-16T00:31:48.511	2012-12-16T00:32:45.515	2012-12-16T00:33:37.430	2012-12-16T00:34:22.773
2012-12-15	L95	2012-12-16T03:33:18.599	2012-12-16T03:34:17.434	2012-12-16T03:35:09.727	2012-12-16T03:35:56.041
2012-12-16	L92	2012-12-17T00:59:48.107	2012-12-17T01:00:45.741	2012-12-17T01:01:37.975	2012-12-17T01:02:25.500
2012-12-16	N2298	2012-12-17T01:07:33.364	2012-12-17T01:08:29.899	2012-12-17T01:09:21.783	2012-12-17T01:10:07.926
2012-12-18	N2298	2012-12-19T03:17:56.649	2012-12-19T03:18:54.884	2012-12-19T03:19:46.978	2012-12-19T03:20:33.321
2012-12-18	L101	2012-12-19T05:38:32.914	2012-12-19T05:39:31.629	2012-12-19T05:40:22.982	2012-12-19T05:41:08.456

Tab. A1: (continue).

2012-12-21	L98	2012-12-22T08:52:41.712	2012-12-22T08:53:38.376	2012-12-22T08:54:30.159	2012-12-22T08:55:15.983
2012-12-21	N2818	2012-12-22T08:59:51.024	2012-12-22T09:00:49.208	2012-12-22T09:01:42.193	2012-12-22T09:02:28.687
2012-12-28	T_Phe	2012-12-29T00:47:20.607	2012-12-29T00:48:19.862	2012-12-29T00:49:12.047	2012-12-29T00:49:57.870
2012-12-28	PG2213	2012-12-29T00:54:11.400	2012-12-29T00:55:08.486	2012-12-29T00:56:00.340	2012-12-29T00:56:46.564
2012-12-28	N2298	2012-12-29T03:26:04.965	2012-12-29T03:27:03.169	2012-12-29T03:27:55.913	2012-12-29T03:28:43.596
2013-01-01	L95	2013-01-02T00:35:59.578	2013-01-02T00:36:58.163	2013-01-02T00:37:50.357	2013-01-02T00:38:36.360
2013-01-01	N2298	2013-01-02T00:42:36.840	2013-01-02T00:43:33.934	2013-01-02T00:44:24.828	2013-01-02T00:45:10.431
2013-01-01	N2298	–	2013-01-02T00:49:04.120	–	–
2013-01-02	L95	2013-01-03T00:18:52.444	2013-01-03T00:19:50.659	2013-01-03T00:20:42.853	2013-01-03T00:21:29.157
2013-01-02	N2298	2013-01-03T00:25:06.974	2013-01-03T00:26:03.768	2013-01-03T00:26:55.132	2013-01-03T00:27:41.126
2013-01-08	L95	2013-01-09T00:26:16.079	2013-01-09T00:27:12.943	2013-01-09T00:28:04.207	2013-01-09T00:28:50.141
2013-01-08	N2298	2013-01-09T00:32:44.530	2013-01-09T00:33:41.263	2013-01-09T00:34:31.597	2013-01-09T00:35:17.361
2013-01-08	N2298	2013-01-09T05:08:28.817	2013-01-09T05:09:25.872	2013-01-09T05:10:17.256	2013-01-09T05:11:03.580
2013-01-31	L95	2013-02-01T01:07:40.436	2013-02-01T01:08:38.491	2013-02-01T01:09:30.205	2013-02-01T01:10:16.558
2013-01-31	N2818	2013-02-01T01:15:06.932	2013-02-01T01:16:02.867	2013-02-01T01:16:54.471	2013-02-01T01:17:39.915
2013-01-31	N2298	2013-02-01T03:37:56.295	2013-02-01T03:38:55.150	2013-02-01T03:39:47.214	2013-02-01T03:40:33.598
2013-01-31	LeoI	2013-02-01T03:44:38.168	2013-02-01T03:45:35.412	2013-02-01T03:46:26.276	2013-02-01T03:47:11.990
2013-01-31	N2818	2013-02-01T05:56:04.254	2013-02-01T05:57:01.789	2013-02-01T05:57:54.393	2013-02-01T05:58:41.266
2013-02-01	N2298	2013-02-02T00:31:07.088	2013-02-02T00:32:05.302	2013-02-02T00:32:57.397	2013-02-02T00:33:43.821
2013-02-01	N2818	2013-02-02T00:38:42.045	2013-02-02T00:39:38.290	2013-02-02T00:40:29.874	2013-02-02T00:41:14.737
2013-02-01	N2818	2013-02-02T03:18:02.909	2013-02-02T03:19:00.153	2013-02-02T03:19:52.628	2013-02-02T03:20:38.931
2013-02-03	N2437	2013-02-04T04:32:33.262	2013-02-04T04:33:32.397	2013-02-04T04:34:24.801	2013-02-04T04:35:10.395
2013-02-03	N5139	2013-02-04T04:40:46.353	2013-02-04T04:41:43.397	2013-02-04T04:42:34.371	2013-02-04T04:43:20.795
2013-02-07	N2818	2013-02-08T05:50:34.518	2013-02-08T05:51:31.743	2013-02-08T05:52:23.717	2013-02-08T05:53:10.431
2013-02-07	L98	2013-02-08T05:57:42.312	2013-02-08T05:58:40.697	2013-02-08T05:59:32.101	2013-02-08T06:00:17.045
2013-02-08	N2298	2013-02-09T00:19:47.717	2013-02-09T00:20:45.391	2013-02-09T00:21:37.325	2013-02-09T00:22:23.739
2013-02-08	N2818	2013-02-09T00:26:54.841	2013-02-09T00:27:51.866	2013-02-09T00:28:43.550	2013-02-09T00:29:29.074
2013-02-08	N2818	2013-02-09T03:37:26.302	2013-02-09T03:38:23.706	2013-02-09T03:39:17.100	2013-02-09T03:40:03.403
2013-02-09	N2298	2013-02-10T00:22:20.949	2013-02-10T00:23:18.873	2013-02-10T00:24:11.248	2013-02-10T00:24:57.521
2013-02-09	N2818	2013-02-10T00:28:54.759	2013-02-10T00:29:51.894	2013-02-10T00:30:43.588	2013-02-10T00:31:29.711
2013-02-09	N2818	2013-02-10T05:11:00.365	2013-02-10T05:11:57.430	2013-02-10T05:12:49.734	2013-02-10T05:13:36.447
2013-02-09	N2818	2013-02-10T09:23:57.685	2013-02-10T09:24:53.929	2013-02-10T09:25:45.142	2013-02-10T09:26:30.626
2013-03-12	N2298	2013-03-12T23:49:45.916	2013-03-12T23:50:42.973	2013-03-12T23:51:33.769	2013-03-12T23:52:19.644
2013-03-12	L101	2013-03-12T23:57:41.840	2013-03-12T23:58:38.927	2013-03-12T23:59:29.632	2013-03-13T00:00:15.698
2013-03-12	E5	2013-03-13T05:35:18.912	2013-03-13T05:36:15.679	2013-03-13T05:37:07.125	2013-03-13T05:37:53.360
2013-03-14	N2298	2013-03-14T23:55:19.137	2013-03-14T23:56:15.973	2013-03-14T23:57:07.419	2013-03-14T23:57:52.614
2013-03-14	L101	2013-03-15T00:02:10.080	2013-03-15T00:03:07.126	2013-03-15T00:03:59.182	2013-03-15T00:04:45.037
2013-03-14	E5	2013-03-15T03:48:44.281	2013-03-15T03:49:43.268	2013-03-15T03:50:36.274	2013-03-15T03:51:22.069
2013-03-14	L104	2013-03-15T05:30:22.318	2013-03-15T05:31:19.575	2013-03-15T05:32:10.820	2013-03-15T05:32:56.736
2013-03-16	N2298	2013-03-16T23:47:27.849	2013-03-16T23:48:28.216	2013-03-16T23:49:23.332	2013-03-16T23:50:14.019
2013-03-16	LeoI	2013-03-16T23:54:44.380	2013-03-16T23:55:41.327	2013-03-16T23:56:32.253	2013-03-16T23:57:17.878
2013-03-16	N2818	2013-03-17T02:59:56.187	2013-03-17T03:00:54.464	2013-03-17T03:01:45.449	2013-03-17T03:02:32.315
2013-03-16	L104	2013-03-17T06:20:15.463	2013-03-17T06:21:13.550	2013-03-17T06:22:05.026	2013-03-17T06:22:51.012
2013-03-16	E7	2013-03-17T09:54:49.166	2013-03-17T09:55:46.453	2013-03-17T09:56:38.548	2013-03-17T09:57:25.374
2013-03-17	N2298	2013-03-17T23:37:51.060	2013-03-17T23:38:51.658	2013-03-17T23:39:45.184	2013-03-17T23:40:31.979
2013-03-17	LeoI	2013-03-17T23:46:25.661	2013-03-17T23:47:22.218	2013-03-17T23:48:13.174	2013-03-17T23:48:58.659
2013-03-17	E7	2013-03-18T10:07:18.278	2013-03-18T10:08:15.224	2013-03-18T10:09:06.720	2013-03-18T10:09:52.956
2013-04-01	N2437	2013-04-01T23:41:01.172	2013-04-01T23:41:57.648	2013-04-01T23:42:48.813	2013-04-01T23:43:34.128
2013-04-01	E5	2013-04-01T23:48:53.414	2013-04-01T23:49:50.642	2013-04-01T23:50:42.027	2013-04-01T23:51:28.462
2013-04-01	N2818	2013-04-02T04:01:05.166	2013-04-02T04:02:02.762	2013-04-02T04:02:54.838	2013-04-02T04:03:41.083
2013-04-02	N2437	2013-04-02T23:46:57.255	2013-04-02T23:47:54.762	2013-04-02T23:48:46.278	2013-04-02T23:49:31.803
2013-04-02	E5	2013-04-03T00:01:52.088	2013-04-03T00:02:53.324	2013-04-03T00:03:43.989	2013-04-03T00:04:29.674
2013-04-02	N2818	2013-04-03T04:10:05.557	2013-04-03T04:11:03.454	2013-04-03T04:11:56.079	2013-04-03T04:12:42.765
2013-04-11	N2437	2013-04-11T23:28:10.963	2013-04-11T23:29:07.989	2013-04-11T23:29:59.225	2013-04-11T23:30:45.010
2013-04-11	E5	2013-04-11T23:36:55.921	2013-04-11T23:37:52.268	2013-04-11T23:38:43.694	2013-04-11T23:39:29.329
2013-04-11	L104	2013-04-12T06:01:31.694	2013-04-12T06:02:31.300	2013-04-12T06:03:23.616	2013-04-12T06:04:10.372
2013-04-12	N2437	2013-04-12T23:13:55.704	2013-04-12T23:14:52.810	2013-04-12T23:15:44.256	2013-04-12T23:16:30.751
2013-04-12	E5	2013-04-12T23:22:58.885	2013-04-12T23:23:55.211	2013-04-12T23:24:45.617	2013-04-12T23:25:32.472
2013-04-12	N2818	2013-04-13T02:19:36.408	2013-04-13T02:20:34.395	2013-04-13T02:21:26.570	2013-04-13T02:22:12.556
2013-04-12	E5	2013-04-13T03:59:33.650	2013-04-13T04:00:30.827	2013-04-13T04:01:22.243	2013-04-13T04:02:08.007
2013-04-12	N5139	2013-04-13T05:50:16.948	2013-04-13T05:51:14.274	2013-04-13T05:52:05.731	2013-04-13T05:52:51.955
2013-04-12	MarkA	2013-04-13T09:22:57.299	2013-04-13T09:23:55.405	2013-04-13T09:24:47.811	2013-04-13T09:25:34.046
2013-04-13	N2818	2013-04-13T23:20:54.713	2013-04-13T23:21:51.769	2013-04-13T23:22:43.515	2013-04-13T23:23:31.401
2013-04-13	L101	2013-04-13T23:27:46.890	2013-04-13T23:28:45.227	2013-04-13T23:29:37.303	2013-04-13T23:30:23.658
2013-04-13	E5	2013-04-13T23:34:27.046	2013-04-13T23:35:24.083	2013-04-13T23:36:14.909	2013-04-13T23:36:59.524
2013-04-13	N2818	2013-04-14T05:21:20.757	2013-04-14T05:22:18.134	2013-04-14T05:23:09.359	2013-04-14T05:23:55.485

Tab. A1: (continue).

2013-04-13	MarkA	2013-04-14T09:24:13.086	2013-04-14T09:25:11.023	2013-04-14T09:26:02.879	2013-04-14T09:26:49.654
2013-05-06	N2818	2013-05-06T23:30:34.324	2013-05-06T23:31:35.670	2013-05-06T23:32:28.976	2013-05-06T23:33:17.502
2013-05-06	PG1323	2013-05-06T23:37:43.993	2013-05-06T23:38:43.400	2013-05-06T23:39:36.016	2013-05-06T23:40:22.301
2013-05-06	E7	2013-05-07T04:44:11.329	2013-05-07T04:45:11.516	2013-05-07T04:46:05.412	2013-05-07T04:46:54.028
2013-05-06	E7	2013-05-07T09:44:42.317	2013-05-07T09:45:42.644	2013-05-07T09:46:37.430	2013-05-07T09:47:26.115
2013-05-09	N2818	2013-05-09T23:09:18.695	2013-05-09T23:10:18.092	2013-05-09T23:11:12.137	2013-05-09T23:12:00.153
2013-05-09	L98	2013-05-09T23:16:32.503	2013-05-09T23:17:32.410	2013-05-09T23:18:25.066	2013-05-09T23:19:12.512
2013-05-09	E7	2013-05-10T06:28:32.743	2013-05-10T06:29:33.239	2013-05-10T06:30:27.096	2013-05-10T06:31:17.801
2013-05-09	E7	2013-05-10T09:27:54.353	2013-05-10T09:28:54.239	2013-05-10T09:29:48.205	2013-05-10T09:30:36.921
2013-05-11	N2818	2013-05-11T22:59:15.069	2013-05-11T23:00:14.996	2013-05-11T23:01:09.222	2013-05-11T23:01:57.747
2013-05-11	L98	2013-05-11T23:06:25.488	2013-05-11T23:07:23.995	2013-05-11T23:08:18.021	2013-05-11T23:09:09.067
2013-05-11	E7	2013-05-12T09:59:28.061	2013-05-12T04:52:21.060	2013-05-12T04:53:23.328	2013-05-12T04:54:15.054
2013-05-11	E7	–	2013-05-12T10:00:27.938	2013-05-12T10:01:21.553	2013-05-12T10:02:08.908
2013-05-26	N2818	2013-05-26T22:50:30.106	2013-05-26T22:51:28.873	2013-05-26T22:52:21.088	2013-05-26T22:53:07.393
2013-05-26	L98	2013-05-26T22:58:23.418	2013-05-26T22:59:19.995	2013-05-26T23:00:11.430	2013-05-26T23:00:57.816
2013-05-27	N2818	2013-05-27T22:53:14.066	2013-05-27T22:54:11.412	2013-05-27T22:55:03.838	2013-05-27T22:55:53.354
2013-05-27	L98	2013-05-27T23:01:38.672	2013-05-27T23:02:35.479	2013-05-27T23:03:27.094	2013-05-27T23:04:12.659

Notes – The filenames are defined by the execution date and time (down to the 1 ms level). Here, only images from the FORS2 detector 1 are shown for reasons of clarity. The corresponding image names from detector 2 are obtained by adding 1 ms to the execution time. Files can be downloaded from the ESO archive: http://archive.eso.org/eso/eso_archive_main.html. The number of images per chip are: 271 (Filter *B*), 274 (Filter *V*), 272 (Filter *R*), and 273 (Filter *I*).