OmegaCAM

OmegaCAM Data Flow System - CALIBRATION PLAN

Implementation of Calibration Requirements

Issue: Version 2.1

Date: 7 Jun 2004

Prepared by: Valentijn, Begeman, Boxhoorn, Deul, Rengelink , Vermey

Purpose of printout: PAE SECOND DELIVERY

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This document is prepared by the Odoco Document Control System.

Version 1.0 has been delivered at the FDR. Following comments at FDR version 1.1 has been prepared, which has been approved by FDR board.

Thus version 1.1 is the FDR formal version.

Changes between Version 1.0–FINAL DESIGN REVIEW and Version 1.1–FINAL DESIGN REVIEW

Additions

New section on 2-3 day cycle specifications – 2.2 DFS requirements.
Specify all three levels of TSF's, as given in VST-SPE-OCM-23100-3064, in requirements.
Detailed estimates of observing times for photometric checks – 2.2 DFS requirements, **req.**562, **req.**563, **req.**564.
Include tilt determination – **req. 571** *Camera focus/tilt*.
CalFile– 562S *Sky brightness* – **req.**562.
Reference to **req.**563 in CA – **req.**564.
OmegaCAM DID – 1.2 Applicable documents.
Once/year dark dome test – **req.**533.
Processing of calibration data follows telescope schedule – 2.2 DFS requirements, 6.1 Data reduction software requirements. Expanded the glossary with all term used in the document.

Updates

Clarify fast recipe for Technical Specifications conformance – **req.**562, **req.**563.
Erroneous references to darkcurrent check for **req. 547** *Quick detector responsivity check* removed.
Nonexistent **CalFile– 561** removed – **req.**533.
Stars have to be observed during the night – **req.**525.
req. 571 *Camera focus/tilt* is no longer a workhorse/*doit* – 1.4 Abbreviations and Acronyms, 5.10 On site quick look analysis.
Exposure times TBC during commissioning – **req.**561.
More accurate description of the algorithm – **req.**523.
Lamp procedure TBC. – 5.4 Detectors operational specific calibrations.
Removed reference to QCO – **seq.– 631**.
Mention acceptance of multi-extension FITS files – **seq.– 631**.
Target-related template parameters (only) where applicable – 4.4 Observing Templates.
Reworded sentence about DFS-pipeline – 5.10 On site quick look analysis.
Reworded sentence about modules – 6.1 Data reduction software requirements.
Rotator *offset* angle – 4.4 Observing Templates.
Use plots for analysis – **req. 571** *Camera focus/tilt*.
Rephrased in terms of provided functionality instead of needed functionality – **7 FUNCTIONALITIES**.

Changes between Version 1.1–FINAL DESIGN REVIEW and Version 2.0–PAE

major changes since FDR

- settling the key bands u',g',r' and i' and filter sets

Minor changes since FDR

- req 534, 535 - uses r'filter
- req 562 - Calfile 562S is split up in its separate photometric bands
- req 569 - Calfile 569 secondary standards, internal now
- req 561 - Emphasize two shutter directions

Additions

CalFile– 548F *Illumination correction fit coefficients* – **req.**548.
CalFile– 562Su *Sky brightness-u'* ,
CalFile– 562Sg *Sky brightness-g'* ,
CalFile– 562Sr *Sky brightness-r'* ,
CalFile– 562Si *Sky brightness-i'* – **req.**562.
Cross-calibration of *composite* vs. *monolithic key* filters **CalFile– 565C** *composite -> monolithic* – **req.**565.
Recipe– PhotCal_Monitoring_Sky for on-line sky spectrum measurement – **req.**562.
INT-La Palma preparatory programme for one square degree secondary standard fields .
Added Appendix A6: sky grid of pointing positions, also used for pixel grid in co-addition

Updates

The *composite* filter is created by a different company from the one that created the *monolithic* filters – **req.**565.
Alternative analysis method for CCD Charge Transfer Efficiency – **req.**534.
CalFile– 533 replaced by **CalFile– 533P** *CCD Linearity Plot* , **CalFile– 533M** *CCD Linearity map* – **req.**533.
CalFile– 563Z,I renamed **CalFile– 563**– **req.**563.
Further specifications of focus/tilt analysis – **req.**571.

Removed

CalFile– 546W *Weightmap* – **req.**546.
On-site on sky health check monitoring using standard fields. This activity, though emphasized at FDR by ESO, was removed on request of ESO. **req. 562** *Monitoring.*

Following these changes CP Version 2.0 has been prepared for PAE.

Changes between Version 2.0–PAE and Version 2.1–PAE

Additions

Calibration Verification Matrix added as Appendix A7.
Figure 3a containing only parts of the data model relevant to ESO-DFS – section 3.
The command-line syntax for each **Recipe**. Clarify which parameters are mandatory and which are optional.
A complete description of each parameter of a **Recipe**.
Valid values or a range of valid values for each parameter of a **Recipe**.
Check reproducibility of filter exchange mechanism – **req. 542** *Flat-field - dome key bands + user bands - doit*.
Typical exposure time added – **req. 543** *Flat-field - twilight*.
Telescope should be tracking – **req. 543** *Flat-field - twilight*.
Jittered observation should be used to remove stars – **req. 543** *Flat-field - twilight*.
In each **req.** where stacking is used, explained why and how this is done.
Recipe– Illumination_Correction_Verify in **req. 548** *Illumination correction* Fully automated recipe to determine illumination correction- description of procedure and recipe.
Recipe– PhotCal_Monitoring_Sky used in **req. 562** *Photometric Calibration - monitoring* .
Recipe– PhotCal_Extract_Resulttable used in **req.**562, **req.**563 and **req.**564.
Documentation for CAT III recipes - **req. 554** *PSF anisotropy* **req. 562** *Photometric monitoring- Sky Brightness monitoring* **req. 548** *Illumination correction- Quick verification*
A description of the reference hardware used for processing has been given.
Suggested QC parameters in **CAP** section.
Output plot for **Recipe– PSF_Anisotropy** included – **req. 554** *PSF Anisotropy*.

Updates

Made names of calfiles in all figures consistent with the nomenclature used in the requirements.
Consistently used the "master" prefix in **CalFile–** name throughout the documentation.
Read noise value and gain are single numbers in the ESO context, not **CalFile–** 's .
Clarified illumination correction procedure – **req. 548** *Illumination Correction*.
Use ADU in output units – **req. 521** *CCD read noise - doit*, **req. 532** *CCD Particle Event Rate*.
TSF section did not refer to read noise template – **req. 532** *CCD Particle Event Rate*.
Changed default values for cold pixel threshold in the text – **req. 535** *CCD Cold Pixels*.
Mention astrometric pre-solution procedure to determine approximate pixel scale and position of reference pixel – **req. 551** *Position of Camera in focal plane*.
Detailed clarification of the objective – **req.**553Telescope and Field Rotator tracking.
In **req.**562, **req.**563 and **req.**564 catalogue derivation and processing of catalogues have

been separated, resulting in a new dataflow. The text of the requirements, the figures, analysis descriptions and data reduction procedures have been updated accordingly.
CalFile– 562u, **CalFile– 562g**, **CalFile– 562r**, **CalFile– 562i** replaced by generic **CalFile– 562T** *Photom + Sky*.
Full re-write of data reduction using MIDAS procedure – **req.**571.
Perform regridding without co-addition in **Recipe– Stare** in **seq.– 632**.
Ordered requirement sections by requirement number, rather than by category.
Made each requirement start at the top of a page.
Processing times updated following measurements with the specified reference hardware.
CAP sections updated to reflect the use of **Recipe** parameters.
Replaced references to "image pipeline" to "image part of the pipeline".
Changed the order of items in each requirement.
Grid on the sky has been fine-tuned – Appendix A6.

Removed
Text related to automatic trend-analysis and verification of pipeline products in all requirements.
Text suggesting that reminiscence can be removed by CCD read out – **req. 536** *CCD Hysteresis, strong signal*.
Text about reminiscence short than 60 seconds – **req. 536** *CCD Hysteresis, strong signal*.

Following these changes CP Version 2.1 has been prepared for PAE.

TABLE of CONTENTS

Lay-out of the sections

1 INTRODUCTION

1.1 Context

This document describes the implementations of the calibration procedures. The Baseline requirements for the Calibrations are given in the URD, while requirements and specifications of the data reduction of both science and calibration data are given in the Data Reduction Specification document (DRS v1.1).

Further implementations and code descriptions are given in Users and Programmers Manual (VST-MAN-OCM-23100-3126).

1.2 Applicable documents

The following documents, of the exact issue shown, form a part of this document to the extent specified herein. In the event of conflict between the documents referenced herein and the contents of this document, the contents of this document shall be considered as a superseding requirement.

[] VST-PLA-OCM-23100-3090 OmegaCAM Calibration Plan V2.0

[] VST-PLA-OCM-23100-3051 OmegaCAM Data Reduction Specifications V1.1

[] VST-PLA-OCM-23100-3100 OmegaCAM Commissioning Plan

[] VST-PLA-OCM-23100-3010 Project Management Plan and Project Plan and Schedule

[] VST-PLA-OCM-23100-3020 Product Assurance Plan

[] VST-PLA-OCM-23100-3080 Technical Operations and Maintenance Plan

S/W deliverables depending on the URD

[] OmegaCAM Data Interface Dictionary

[] OmegaCAM Template Signature Files

[] OmegaCAM Exposure Time Calculator

1.3 Reference documents

The following documents are referenced in this document.

[] VLT-SPE-ESO-19000-1618 1.0 21/04/1999 — VLT Data flow for the VLT instruments Requirement Specification

[] MoU OmegaCAM - ESO

[] VST-PLA-OCM-23100-3030	Safety Analysis and Compliance Assessment
[] VST-TRE-OCM-23100-3040	Design Analysis, Performance Report
[] VST-TRE-OCM-23100-3041	Design Analysis, Performance Report: Mechanical
[] VST-ESO-OCM-23100-3042	Design Analysis, Performance Report: Detector System
[] VST-TRE-OCM-23100-3043	Design Analysis, Performance Report: Electronic
[] VST-SPE-OCM-23100-3050	Data Flow System User Requirements
[] VST-SPE-OCM-23100-3060	Instrument Software
[] VST-SPE-OCM-23100-3064	OmegaCAM Observation Software Design Description
[] VST-PLA-OCM-23100-3070	MAIT and Alignment Plan
[] VLT-MAN-ESO-19000-2050	FTU FITS Translation Utility User Manual
[]	SExtractor v2.3 User's manual
[]	Eclipse User's Guide - April 1, 2002
[]	FFTW manual 3.0.1
[]	The LDACTools Library v1.2 User's guide
[]	Pipeline Documentation Ver. 1.3
[]	SWarp v2.0 User's guide

1.4 Abbreviations and Acronyms

Abbreviations and Acronyms used in this document

A/D	Analog/digital
ACS-dbase	Astronomical Calibration Source database
ADC	Atmospheric Dispersion Corrector
ADU	Analog to Digital Unit
AGN	Active Galactic Nucleus
BRD	Baseline Requirements Document
CA	Calibration Analysis
CAP	Calibration Analysis Procedure
CCD	Charge Coupled Device
CO	Calibration Observation
CP	Calibration Plan
CTE	Charge Transfer Efficiency
CVS	Code Version System
DFS	Data Flow System
ESO	European Southern Observatory
ETC	Exposure Time Calculator
FOV	Field of View
FWHM	Full Width at Half Maximum
GRB	Gamma Ray Burst
GT	Garanteed Time

HZSS	High Redshift Supernova Search
ICS	Instrument Control Software
IWS	Instrument Workstation
ISO	Infrared Space Observatory
IST	Instrument Science Team
KBO	Kuiper Belt Object
MoU	Memorandum of Understanding
NOVA	(Dutch) Nederlandse Onderzoekschool Voor Astronomie
OaPd	Astronomical Observatory of Padua
OB	Observation block
OD	Observation Description
OPC	Observing Programme Committee
OT	Optical Transient
OT	Observing Template
PPP	Photometry Preparatory Programme
PSF	Point Spread Function
QC0	Quality Control zero
QC1	Quality Control one
QSO	Quasi-Stellar Object
RPE	Relative Pointing Error
RP	Routine Phase
RSRF	Relative Spectral Response Function
RTD	Real Time Display
SCP	Supernova Cosmology Project
SED	Spectral Energy Distribution
SSO	Solar System Object
S/N	Signal/Noise
S/W	Software
TBC	To Be Confirmed
TBD	To Be Defined
TBW	To Be Written
TCS	Telescope Control System
TP	Target Package
TSF	Template Signature File
URD	User Requirement Document
USM	Universitäts Sternwarte München
VLT	Very Large Telescope
VST	VLT Survey Telescope
WFI@2.2m	Wide Field Imager at the ESO 2.2m telescope

2 SCIENTIFIC REQUIREMENTS -see URD

3 INSTRUMENT CONCEPT- Summary -see URD

4 OBSERVING MODES and STRATEGIES - see URD

Observing modes, observing strategies and the list of required science data observing templates are given in the URD. The CP specifies, in addition, the OTs required for calibration purposes (Section 4.4).

4.4 Observing Templates

The Observing Templates for **OmegaCAM** are defined in Instrument Software Functional Specifications (VST-SPE-OCM-23100-3064). The following calibration Templates are used.

- **TSF– OCM_img_cal_bias**
  Acquire N bias exposures, with opaque filter in optical path and shutter closed.
    - **TSF– OCM_img_cal_readnoise**
      Bias exposures with $N = 2$
- **TSF– OCM_img_cal_dark**
  Acquire N dark exposures, with opaque filter in optical path and shutter closed.
- **TSF– OCM_img_cal_skyflat**
  Acquire N sky (twilight) flats, through a given filter.
- **TSF– OCM_img_cal_domeflat**
  Acquire N dome flats. Telescope is preset to point towards the flat-field screen (without tracking), lamps must be switched on.
    - **TSF– OCM_img_cal_gain**
      Domeflat exposures with $t_{exp} = 2, 60, 50, 4, ..., 4, 50, 60, 2$
    - **TSF– OCM_img_cal_cte**
      Domeflat exposures with $N = 10$
    - **TSF– OCM_img_cal_quick**
      Domeflat exposure with $N = 1$ and filter=composite
    - **TSF– OCM_img_cal_shutter**
      Domeflat exposres with $t_{exp} = 10, 0.1, 0.1, 10$

In addition the following science templates are used

- **TSF– OCM_img_obs_stare**
  - **TSF– OCM_img_obs_monit**
    Stare observations with $N = 1$, filter=composite
  - **TSF– OCM_img_obs_zpkey**
    Stare observations with $N = 1$, filter=key band
  - **TSF– OCM_img_obs_zpuser**
    Stare observations with $N = 1$, filter=user band

5 BASELINE CALIBRATION REQUIREMENTS

5.0 Documentation system, Odoco

The trajectory of the data through the DFS shall be guided by the **OmegaCAM** documentation system, **Odoco**. The set-up of the specifications of the calibrations and its data reduction is done in purely requirement driven fashion.

The calibration documentation system (**Odoco**) is a collection of files which contains a description of both the requirements on **OmegaCAM** calibrations, as well as detailed descriptions of the envisaged Calibration Observations (**CO's**) and their analysis and data-reduction. The **Odoco** is meant to avoid unnecessary duplication of work for the documentation of the various stages of the project; from the definition of basic requirements, to implementations and final operation and user manuals. It should also aid the documentation of development work. The **Odoco** was originally developed for ISO and provided a full uplink system (IOCD). The present version, adapted for **OmegaCAM**, contains essentially only the part which deals with text, pseudo code, recipe's and automatic document creation. The **Odoco** system is essentially a set of TeX macros, with LaTeX emulation, together with some supporting C routines. The whole present document is generated by **Odoco**, but particularly this section, listing the baseline calibration requirements, uses some more advanced **Odoco** options.

The very strict document control of the original IOCD will not be maintained, but **CVS** (Concurrent Versions System) will be used for local versioning control. Official versions of documents shall be filed separately.

The contents of the **Odoco** will be continuously evolving and fonts are chosen for optimal reading on a computer monitor screen.

In **Odoco**, calibrations are specified under requirement subsections (**req.**'s) which are labeled with 3-digit numbers. Each subsection contains a number of items: e.g. the **objective** of the requirement, a description of a specific Calibration Observation or a cross-reference to the use of a CO that has been defined under another requirement. Also, the end-results have been specified and the text contains various descriptions for both Template Signature Files (**TSF**'s) which define the creation of the observation blocks (**OB**) and for the off-line data analysis. Overall priorities have been defined (essential, very important, desirable) and are specified under the item **priority**.

The chosen items for the descriptions of the requirements (**req.**'s) match well to the items needed for the **recipes** for DFS data reductions. In section 6.1 complete listings of both the **req.** items and the **recipe** items are given. The **req.**'s as listed in the **Odoco** will eventually evolve into the deliverable recipe's.

The **Odoco** is designed to provide a comprehensive and accessible documentation system of the various activities that relate to the **OmegaCAM** calibrations. It serves a variety of purposes, and facilitates the extraction of text from the **Odoco** data base into complete documents. The **Odoco** can provide the following documents:

1. **A listing of the Baseline OmegaCAM Calibration Requirements. Odoco** contains an up-to-date listing of all the baseline requirements for the **OmegaCAM** calibrations, i.e. for each requirement (**req.**) the text under the items: **Objective, When performed/frequency, Required accuracy, Priority**. See section 5 of the URD.
2. **Full documentation of the OmegaCAM calibration plan**. A detailed description of all the **OmegaCAM** calibration requirements and their implementations. See Section 5 of the Calibration Plan. Summary sections (two digit sections) have been introduced for a variety of calibration activities: e.g. detector specific calibrations, photometric calibrations etc. A general overview of the **OmegaCAM** calibrations can be obtained by printing the summary sections of the **Odoco**. In order to further ease the readability of this document, both each requirement and each calibration analysis procedure text item begins with a 'one-liner' stating the overall idea.
3. **A description of the Template Signature File necessary to produce observation blocks, TSF's.** When a requirement can not be fulfilled by means of data analysis of observations made for another requirement, **Odoco** contains a detailed description of the instrument configuration and procedures under the items **Sources, observations** and **TSF**, (TSF, Template Signature File). Note, the term **selfstanding** has an important meaning: when a requirement is selfstanding, it will normally propagate as a single dedicated calibration observation, with a single dedicated data reduction task. Conversely, non-selfstanding requirements will have more complex dependencies and often involve a data reduction of data taken for another selfstanding requirement.
   Under the item **TSF** the hierarchical structure of observation specifications is detailed (when applicable) on different lines:
   - first line: observing **Strategy**–
   - second line: observing **Mode**– N=
   - third line: generic/base **TSF**–
   - fourth line: specific/dependent == **TSF**–
4. **Description of Calibration Analysis (CA).** For each requirement, a specification of the data analysis related to the requirement is given under the item **CA**. Standard functionalities can be quoted in the optional item **Needed functionalities for CA**. A detailed description of the implementation, which could include guidelines for the data analysis or pseudo code is given under the items **CAP** (Calibration Analysis Procedure). **Inputs and Outputs** defines the various calibration tables. Thus a document listing all the text of the items **CA**, **CAP** and **Inputs and Outputs** gives a complete overview of the Calibration data reduction analysis.

5. **A reference document for timelining** OmegaCAM **Calibration observations.** The items **When performed/frequency and Estimated time needed** can be used to design a detailed **Schedule** of calibration observations both in the commissioning phase (**CP**) and during the Routine Phase (**RP**).
6. **A listing of the various requirements for an Astronomical Calibration Source data base, (ACS-dbase).**
7. The **recipes** belonging to the execution of requirements.

As **Odoco** can provide various documents with a different filtering of the source of information, each printout contains a table, listing the selection criteria. Also, the status of the printout is marked (formal issue, or private workcopy). Each printout contains this section.

On the following pages a print-out is included which is believed to be relevant for the present document.

OmegaCAM

OmegaCAM Data Flow System - CALIBRATION PLAN

Implementation of Calibration Requirements

Issue: Version 2.1

Date: 7 Jun 2004

Prepared by: Valentijn, Begeman, Boxhoorn, Deul, Rengelink , Vermey

Purpose of printout: PAE SECOND DELIVERY

Selected items from Odoco file system	
Summary sections	•
Items:	
Objective	•
Fulfilling or fulfilled by	•
When performed/frequency	•
Sources, obs.,. . .	•
Inputs	•
Outputs	•
Required accuracy, constraints	•
Estimated time needed	•
Priority	
Template Signature File	•
Recipe	
Calibration Analysis spec's	
Needed Functionalities	
CA implementation (pseudo code)	
Status of Req.	
FLAG	

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This document is prepared by the Odoco Document Control System.

LAY-OUT of BASIC CALIBRATION REQUIREMENTS DETECTOR RELATED

5.1	**Functional Checks**	
5.2	**Electronics specific**	
5.2.1	CCD read noise - *doit*	**CalFile– 521**
5.2.2	CCD hot pixels	**CalFile– 522**
5.2.3	CCD gain	**CalFile– 523**
5.2.4	Electromagnetic compatibility	
5.2.5	Electrical cross talk	
5.3	**Detectors specific**	
5.3.1	CCD Dark current - *doit*	**CalFile– 531**
5.3.2	CCD Particle event rate	**CalFile– 532**
5.3.3	CCD linearity	**CalFile– 533(PM)**
5.3.4	CCD Charge transfer efficiency	**CalFile– 534**
5.3.5	CCD Cold pixels	**CalFile– 535**
5.3.6	CCD hysteresis	**CalFile– 536**
5.4	**Detectors operational**	
5.4.1	Bias - *doit*	**CalFile– 541**
5.4.2	Flat field - Dome	**CalFile– 542(L)**
5.4.3	Flat field - Twilight	**CalFile– 543**
5.4.4	Flat field - Night sky	**CalFile– 544**
5.4.5	Flat field - fringing	**CalFile– 545**
5.4.6	Flat field - master flat	**CalFile– 546**
5.4.7	Quick detector check	**CalFile– 547(r)**
5.4.8	Illumination correction	**CalFile– 548**

LAY-OUT OF BASIC CALIBRATION REQUIREMENTS cont'd

5.5	**Astrometric**	
5.5.1	Focal plane position of camera	
5.5.2	Telescope Pointing	
5.5.3	Telescope and rotator tracking	
5.5.4	PSF anisotropy	**CalFile– 554**
5.5.5	The astrometric solution - *doit*	**SeqFile– 634(CR)**
5.5.6	Astrometry - Guide CCD's	**CalFile– 556**
5.6	**Photometric**	
5.6.1	Shutter timing	
5.6.2	Photometric monitoring	**CalFile– 562(T)**
5.6.3	Zeropoint key bands *doit*	**CalFile– 563**
5.6.4	Zeropoint user bands	**CalFile– 564**
5.6.5	Filter band pass - user– >key	**CalFile– 565(C)**
5.6.6	Rotation angle - ADC, rotator	
5.6.7	Linearity	
5.6.8	Detection limit	
5.6.9	Secondary standards	**CalFile– 569**
5.7	**Alignment**	
5.7.1	Camera focus/tilt	
5.7.2	Ghosts - ADC	
5.8	**Telescope**	
5.9	**End to end tests**	

5.1 Functional Checks

The commissioning plan [VST-PLA-OCM-23100-3100] lists a large set of acceptance tests. Most of these test are engineering tests and are not repeated here. Those engineering tests which can be executed with requirements from the URD/CP contain the proper reference to the URD in the commissioning plan.

The technical operations and maintenance plan [VST-PLA-OCM-23100-3080] describes activities during **Routine Phase (RP)**. Both the URD, CP and the DRS specifies the requirements and the activities for fulfilling these requirements during RP. The label RP always points to activities that shall be followed in the technical operations and maintenance plan.

5.2 Detector Electronics specific Calibrations

Section 5.2 contains the requirements for the characterization of the detector system on electronics level, while Section 5.3 lists more detector specific calibrations. The separation between these Sections is somewhat artificial. In Section 5.4 more daily characterizations are listed, which involve the flatfielding and de-biasing. Requirements which are foreseen to become 'workhorses' are labeled with *doit*, e.g. a quick daily evaluation of the read noise serves as a daily health check.

The CCD's are operated at one port; **electrical cross talk** is not expected to significantly affect the observations. However, as a check, the absence of significant cross-talk is verified (**req.**525).

The **hot pixel** (**req.**522) and **cold pixel** (**req.**535) characterization are combined in the **individual weight maps** (**seq.– 633).**

As the standard read-out time of the arrays is already very fast, $\sim$ 40 sec , no extra fast **read-out mode** is supported in the characterization.

CCD **rebinning mode** and **windowing mode** are not supported in the calibration and data reduction procedures.

5.2.1 Req. — *CCD read noise - doit*

Objective:

Measure the CCD read noise (in ADU's) as a standard health check.

The read noise is measured from pairs of bias exposures. The rms scatter of the differences between two exposures is computed and divided by $\sqrt{2}$. Monitor variations. This is the first order daily health check.

Fulfilling or fulfilled by:

Selfstanding

Required accuracy, constraints:

Readout noise less than 5e$^-$.

Variation in readout noise w.r.t. reference value less than 0.5e$^-$.

These are lab values. The corresponding limits in ADU can be calculated using the e^-/ADU conversion factor from **req.**523.

When performed/frequency:

daytime- Commissioning, during all operations: daily health check.

Estimated time needed:

Observation: 5 min. Reduction: 5 sec/CCD.

Inputs:

2 raw bias frames **CalFile– 521** *Readout noise* older versions

Outputs:

CalFile– 521 *Readout noise* in ADU's
The **CalFile** correponds to QC parameter read_noise (a single number).

TSF:

Mode– Stare N=2
(**TSF– OCM_img_cal_bias,** N=2)
= **TSF– OCM_img_cal_readnoise**

5.2.2 Req. — *hot pixels*

Objective:

Determine CCD bad/hot pixels.

5σ outliers in the master bias frame are bad-hot pixels. These pixels should be recorded and ignored (assigned a weight of 0) in dedithering and dejittering, as well as source extraction. For this purpose the bad/hot pixel map is used to assign a weight of zero to the affected pixels in the weight map (**seq.– 633).**The search for hot pixels would also identify traps.

Fulfilling or fulfilled by:

Additional data reduction of **CalFile– 541** *Master Bias frame* to determine cold pixels

Required accuracy, constraints:

Number of hot pixels to be determined by experience/lab values.
The total number of bad pixels (hot pixels + cold pixels) is less than 80000 (checked in **req. 535** *Cold pixels*
Difference in number of hot pixels w.r.t. reference value, less than 100.

When performed/frequency:

daytime- Commissioning, in RP twice per week.

Estimated time needed:

Observation: None. Reduction: $<$ 20 sec./CCD.

Inputs:
CalFile– 541 *Master Bias frame*
CalFile– 522 *Bad/hot pixel map* previous version

Outputs:
CalFile– 522 *Bad/hot pixel map, number of hot pixels*

TSF:
Use master bias (**req.**541)

5.2.3 Req. — *CCD gain*

Objective:
Determine CCD gain and variation with time
Determine the conversion factor between the signal in ADU's supplied by the readout electronics and the detected number of photons (in units e^-/ADU) and monitor variations in time.
The gain factors are needed to convert ADU's in raw bias-corrected frames to the number of electrons, i.e. detected photons.
Take two series of 10 dome flatfield exposures with wide range of exposure times. Derive the rms of the differences of two exposures taken with similar exposure (integration time). Exposure differences of pairs should not exceed 4%. The regression of the square of these values with the median level yields the conversion factor in e^-/ADU (assuming noise dominated by photon shot noise).

Fulfilling or fulfilled by:
Selfstanding, also measures detector linearity (**req.**533).

Sources, observations, instrument configurations:
Dome flat field exposures on lamp, with t_{int}= 2, 60, 50, 4, 8, 40, 30, 1, 16, 24, 24, 16, 1, 30, 40, 8, 4, 50, 60 and 2 seconds. Use r' filter.

Required accuracy, constraints:
Accuracy: In units of e^-/ADU, from lab values or found empirically. Variation in time less than 1%.

When performed/frequency:
daytime- Commissioning, in RP once week.

Estimated time needed:
Observations: 1 hour. Reduction: 3 min./CCD.

Inputs:
CalFile– 541 *Master Bias frame*
CalFile– 523 *Conversion factor e^-/ADU* older versions.

Outputs:
CalFile– 523 *Conversion factor e^-/ADU*
The **CalFile– 523**corresponds to the QC parameter gain (single number).

TSF:

Mode– Stare N=20
(**TSF– OCM_img_cal_domeflat,** t_{exp}= 2, 60, 50, 4, 8, 40, 30, 1, 16, 24, 24, 16, 1, 30, 40, 8, 4, 50, 60, 2 s.).
= **TSF– OCM_img_cal_gain**

5.2.4 Req. — *Electromagnetic Compatibility*

Objective:

Verify whether any external source (e.g. dome drives, control systems) is not interfering in the CCD overall detector system, leading to additional, mostly non-white noise.
Technical specifications require less than 20% effect on read-out noise, for external interference and less than 10% effect on read-noise for internal **OmegaCAM** interference.
If electronic interference occurs then this will put constraints on the operation of the instrument. For example, if interference occurs during movement of the telescope, one cannot read the CCDs and move the telescope at the same time,.
Interference is detected by measuring the read noise (**req.**521) under operational conditions. This means doing bias measurements while the telescope and/or dome are moving.

Fulfilling or fulfilled by:

repetition of CCD read noise calibrations **req.**521.

Sources, observations, instrument configurations:

Raw bias frames obtained while the telescope/dome are moving.

Required accuracy, constraints:

Difference between read noise under operational conditions and the standard read noise measurement should be smaller than 20% for external and 10% for internal causes of interference.

When performed/frequency:

Day time; Commissioning; once a year; every time a major system change has been made; To be determined by experience

Estimated time needed:

Observations: 4 hours. Reduction: 1 min./CCD.

Inputs:

raw bias frames, obtained when telescope/dome were moving.
CalFile– 521 *CCD read noise*

Outputs:

OK/non-conformance flag.

TSF:

Mode– Stare N=2
(**TSF– OCM_img_cal_bias,** N=2)
= **TSF– OCM_img_cal_readnoise** while telescope and/or dome are moving.

5.2.5 Req. — *Electrical cross talk*

Objective:
Although crosstalk is not detectable in the WFI, and only one part per CCD is used, the sharing of one FIERA by 16 CCD's opens up the possibility of cross talk.
Observe a bright (mag 5-8) star at 16 different chips (1 FIERRA serves 16 chips).

Fulfilling or fulfilled by:
Selfstanding

Sources, observations, instrument configurations:
Bright star, mag 5-8

Required accuracy, constraints:
10^{-5}

When performed/frequency:
Nighttime. Commissioning.

Estimated time needed:
5 minutes

Outputs:
Conformance flag

TSF:
Mode– Stare N=1
(**TSF– OCM_img_obs_stare,** N=1, filter=key band)

5.3 Detectors specific calibrations

5.3.1 Req. — *CCD Dark Current - doit*

Objective:

Measure CCD dark current (in ADU/pixel/hour) for qualification purposes of the detector chain (qualification and trend analysis). The particle event rate will be determined on the fly.
Repeating the test with the dome lights on will provide information on possible light leaks.
Three one hour exposures are taken with the shutter closed. After rejection of the cosmic ray events, the signal above the bias level is the dark signal.
For the reduction of the science observations the subtraction of the sky brightness will include the dark current, and a separation of both contributions is normally not required.
Do a trend analysis.

Fulfilling or fulfilled by:

Selfstanding, also used to compute the particle event rate.

Sources, observations, instrument configurations:

Three 1 hour exposures with shutter closed. Dome lights either on or off for all exposures.

Required accuracy, constraints:

Dark count rate should be less than the equivalent of 3 e^-/pixel/hour in ADUs excluding bad pixels.
Accuracy of determining particle event rate 1 ADU/cm^2/hour.
Particle event rates should be identical for each chip.

When performed/frequency:

Daytime (if dome and camera are proven to be light tight enough) - Commissioning; once per week. Alternatively, one dark frame per day could be taken, followed by a trend analysis once/month.

Estimated time needed:

Observation: 3 hours. Reduction: $<$ 1 min./CCD.

Inputs:

3 raw dark frames
CalFile– 541 *Master Bias frame*
Lab values
CalFile– 531 *Dark count rate for each CCD* older versions.
CalFile– 532 *Particle event rate* older version.

Outputs:

CalFile– 531 *Dark count rate for each CCD* in ADU/pixel/hour
CalFile– 532 *Particle event rate* in events/cm^2/hour
In ESO DFS terminology these outputs are not a **CalFile**, but a single number.

TSF:

Mode– Stare N=3
TSF– OCM_img_cal_dark exposure time 1 hour each, shutter closed. Dome lamp either on or off for all exposures

5.3.2 Req. — *CCD Particle Event Rate*

Objective:

Determine CCD particle event rate by evaluating dark current measurements.

Verify the absence of a local radiation source affecting the detector. The data will be inspected for significant differences of the rates on different chips, and will be screened for local effects.

Fulfilling or fulfilled by:

Data reduction of **req. 531** *Dark current*

Required accuracy, constraints:

better than 1 ADU/cm^2/hour

When performed/frequency:

Commissioning and when dark current is measured.

Outputs:

CalFile– 532 *Particle event rate* in events/CCD/hour

5.3.3 Req. — *CCD Linearity*

Objective:

Characterize the linearity of the system over the full dynamic range of the A/D converter.

Both the overall absolute linearity of the system and the pixel-to-pixel variation in linearity are of interest.

The overall linearity of the system can be obtained by measuring the counts as a function of exposure time for a series of dome flats. The data to use for this can be the same as for the measurement of the Gain (**req.**523, q.v.)

The pixel-to-pixel variation in the linearity is obtained by dividing a flatfield with a mean exposure level of more than 30000 ADU by a flatfield with an exposure level of less than 1000 ADU. Pixels that deviate more than 5σ from the mean, in this divided image, have an anomalously high nonlinearity. This map of nonlinear pixels may be used in conjunction with the hot and cold pixel maps to produce a map of bad pixels. One can use suitable long and short exposures from the measurements of the Gain (**req.**523, q.v.) for this.

In addition, during a cloudy night, once per year, the linearity will be checked by taking various exposures with a variety of exposure times on the dome screen. These data will be subject to interactive analysis.

Fulfilling or fulfilled by:

Data reduction of **req. 523** *CCD Gain*

Required accuracy, constraints:
better than 1% on the photometric scale

When performed/frequency:
daytime- Commissioning, in RP once per month, dark dome test once/year

Estimated time needed:
Observation: None

Inputs:
Raw dome flatfields
CalFile– 541 *Master Bias frame*

Outputs:
CalFile– 533P *CCD Linearity Plot* A measure of the overall nonlinearity can be obtained from this plot

CalFile– 533M *CCD Linearity map* A map of (anomalously) non-linear pixels can be used in conjunction with hot and cold pixel maps.

TSF:
Use same raw data as for **req. 523** *CCD gain*

5.3.4 Req. — *CCD Charge Transfer Efficiency*

Objective:
Characterize horizontal and vertical transfer efficiency (CTE) per single transfer (in units of the fraction of the charge actually transferred).
Taken from WFI@2.2m: Ten flatfields are taken with 50 vertical and 50 horizontal overscan pixels and a mean exposure level of about 20000 ADU's. The mean is computed and corrected for the bias. Average signal levels are determined in the two overscan regions as well in the light sensitive pixels just preceeding the respective overscan pixels. Any signal found in the overscan pixels was due to non-unity CTE lost from the neighbouring light-sensitive pixels. The fractional charge still remaining in the light-sensitive pixels is the CTE.
Note added after analysing Bias behaviour in overscan regions on OmegaCAM CCDs (see test report Notes on OmegaCAM bias level- Nov 2003): The test report shows that there is significant reminiscence in the detector/amplifier chain with typical time scale of about a second. Therefore both the vertical and the horizontal overscan regions are affected by this reminiscent signal (only the upper 50 rows of the Y-overscan region are free from this signal). Thus the above decribed method for WFI is not expected to deliver very useful information on CTE.
Alternative: it might be more practical and informative to inspect the tails in X and Y of very bright stars.

Fulfilling or fulfilled by:
selfstanding but related to masks for **req. 541** *Bias - doit*, **req. 522** *Hot pixels* and **req. 535** *CCD Cold Pixels*.

Sources, observations, instrument configurations:
Dome flat field- lamp. Use r' filter.
Alternative none- use **req. 525** *crosstalk*.

Required accuracy, constraints:
CTE $>$ 0.999995 per parallel or serial shift.

When performed/frequency:
daytime- Commissioning, in RP once half year *alternative* additional data reduction of **req. 525** *Cross talk*

Estimated time needed:
30 min.

Inputs:
CalFile– 541 *Master Bias frame*

Outputs:
CalFile– 534 *charge transfer efficiency factors*

TSF:
Mode– Stare N=10
(**TSF– OCM_img_cal_domeflat,** N=10)
= **TSF– OCM_img_cal_cte**

5.3.5 Req. — *CCD Cold Pixels*

Objective:
Identify cold pixels.

Cold pixels should be recorded and ignored (assigned a weight of 0) in dedithering/dejittering and source extraction. For this purpose the bad/cold pixel map, together with the hot pixel map (**req.**522) is used to assign a weight of zero to the affected pixels in the weight map (**seq.– 633**).
Cold pixel maps are constructed from reduced dome (**req.**542) or twilight (**req.**543) flats. The flatfield is smoothed. The smoothed flat is used to flatten the flat. In this flatfielded image, pixels that are outside a given range (0.96-1.04) are taken to be cold pixels. Note that this invalidates any pixel whose gain differs significantly from its immediate neighbours. In particular, this also identifies pixels that are bright relative to their neighbours as "cold". Note, that pixels above the threshold are formally not "cold", but are flagged annyway. In the end, hot plus cold pixel map are combined in weightmap.

Fulfilling or fulfilled by:
Requires data reduction of master domeflat (**req.**542) or twilight (**req.**543) flat frames.

Sources, observations, instrument configurations:

Use master dome- or twilight flat. Use r' filter.

Required accuracy, constraints:

Quality Check: Number of hot pixels to be determined by experience/lab values. The total number of bad pixels (hot pixels + cold pixels) is less than 80000. Difference in number of cold pixels w.r.t. reference version less than 100.

When performed/frequency:

daytime- Commissioning, in RP once per 3 months.

Estimated time needed:

Observation: None. Reduction: $<$ 20 sec./CCD.

Inputs:

CalFile– 535 *Cold pixel map* previous version
CalFile– 542 *Dome flat* or **CalFile– 543** *Twilight flat*

Outputs:

CalFile– 535 *Cold pixel map*

TSF:

Use master dome- (**req.**542) or twilight flat (**req.**543)

5.3.6 Req. — *CCD Hysteresis, strong signal*

Objective:

Quantify the effect of CCD signal reminiscence at timescales *larger* than 60 sec.

Reminiscence of a strong signal (a saturated star) in subsequent observations ("ghosts") is a potentially debilitating problem for data reduction and interpretation. The absence of this effect should be verified by observations of very bright objects and subsequent dark exposures.

If "sources" are detected in the dark frames at the pixel positions of bright sources in the first field, signal reminiscence is a problem, which can be characterized by the decay time of a strong signal.

Fulfilling or fulfilled by:

Selfstanding

Sources, observations, instrument configurations:

Observe a field containing very bright objects followed by a few dark exposures. Number of dark exposures to be determined by experience.

When performed/frequency:

Commissioning.

Estimated time needed:

30 minutes

Outputs:

When significant effect is detected:
CalFile– 536 *CCD Hysteresis*, containing the signal decay time.

TSF:

Mode– stare N=2
TSF– OCM_img_obs_stareand **TSF– OCM_img_cal_dark**

5.4 Detectors operational specific calibrations

In this Section **req.**'s are listed which are essential related to the daily operations of the acquisition of the science data.

For all detector and photometry related calibrations each CCD is characterized independently of the others. (Only in the case of astrometric solutions, data of various chips is combined).

A **set of calibration lamps** together with a **dome screen** is used to monitor the health of the instrument and to measure the fine structure of the flatfield.

The calibration lamp system contains two **sets** of 4 commercial 12-24V halogen lamps each. Each set is operated independently. Each set is stabilized in current supply (one unit for whole set). Lamps are switched on/off with a gradual increase/decrease of the current over a timespan of 3-5 minutes. Implementation TBC. When operated this way, the nominal lamp instabilities are expected to be of the order of 0.05%/hour for a timespan of 200 hours of lamp operations (private comm. Philips Labs). For a nominal 1-2 hour/day of operations the lamp instability is expected to be of the order 1.5-3 % per month. The lamp instabilities are expected to be strictly linear after 100 hours of operations. When operating two sets at different rates, say one set 1 hour/day the other set at say 1 hour/two weeks a full characterization of the lamp stability can be achieved at accuracies better than a few percent on a monthly basis. Also continuity after failure of one lamp can be obtained. The accuracy is better than required as also other factors, like dust on the lamps and background light will affect the effective illumination of the screen. Altogether, the system is expected to provide control over the illumination of the screen with an accuracy better than 5-10%, which will be used for a daily health check on the overal throughput/health of the detectors (**req. 547** *Quick detector responsivity and health check*). This activity provides a deliberate redundancy with flatfield measurements on the dome screen (**req. 542** *Flat field – dome key bands–doit*), in order to provide the necessary cross-check in the off-line calibration analysis procedures. Next to the health checks taken during the night, a standard health check using a photometric standard field (also providing the absolute photometry is specified in **req. 562** *Photometric Calibration – Monitoring*). The system of lamps, flatfields measurements, quick checks using the lamps and health checks on the sky on photometric standard fields is designed to support the photometric calibration of a Survey System, for many years to come. The system provides redundancy faciltating cross-checks and has a typical maintenance/update frequency once/month.

The calibration of science data can be divided in three steps.

1 Removing the effects of bias and differential gain.

2 Relating the overall gain, and hence counts $S(x, y)$ to a photometric scale

3 Relating the x, y coordinates to an astrometric reference system.

The raw science and standard images record $S(x, y)$ counts in pixel x, y, that are related to the incident photon flux $I(x, y, \lambda)$ by:

$S(x, y) = b(x, y) + G \int g(x, y, \lambda)I(x, y, \lambda)d\lambda,$

with G the ADU conversion factor, $g(x, y, \lambda)$ the quantum efficiency or **gain** as function of position and wavelength, and $b(x, y)$ the bias offset.

The photometric and astrometric calibration (steps 2 and 3) are the subject of Sections 5.5 and 5.6, respectively. Here we list the calibration data necessary to remove the effects of bias and gain variation over the image. These calibration data include:

- **Bias** to subtract residual pattern in the bias offset.
- **Flatfields** to correct for non-uniform gain.
- **Fringe maps** to remove the fringe-patterns
- **Weight maps** to determine the relative contribution of each pixel when image data are combined,

A first-order approximation of the bias level in an image is provided by the median of the overscan region. A more accurate determination of the bias offset takes into account the following two effects: i) the bias level grows to its asymptotic level in the first few hundred lines, and ii) the bias level depends on the total signal in a given line. Therefore, an initial bias correction—the **overscan correction**, is applied by averaging the overscan pixels for each line, and subtracting this value from that line. Also, experience with the WFI has shown the presence of residual patterns in the bias offset over the image area. Under the assumption that these patterns are also present in **OmegaCAM** data its characterization by means of a master bias frame is specified in **req.**541.

Note that the **OmegaCAM** calibration and image pipelines support several overscan correction methods (not doucumented separately in every requirement). It is imperative that all calibration data is derived using the same overscan correction method.

The gain, $g(x, y, \lambda)$, incorporates the wavelength-dependent pixel-to-pixel variation in transmissivity of the different lightpaths through the telescope optics, filters and detectors. The gain can be approximated with

$$g(x, y, \lambda) = g_{DQE}(\lambda) g_{ff}(x, y),$$

with $g_{ff}(x, y)$ the pixel-to-pixel variation in the gain, and $g_{DQE}(\lambda)$ the overall detector quantum efficiency (zeropoint), at $g_{ff} = 1$, which is subject to photometric calibration (Section 5.5).

The characterization of the pixel-to-pixel variation of the gain, the **flatfield**, is obtained by observing a spatially uniform source of illumination. A normalized version of such an image provides a measure of the relative variation of the gain over the image area, $g_{ff}(x, y)$. Note that this flatfield measures a combination in the pixel-to-pixel gain variation and the variation in transmissivity of the different light paths through the telescope optics and filters.

The ideal flatfield observation is:
i) uniformly illuminated
ii) bright, to minimize errors due to photon noise,
iii) of constant color, preferably a color that is the same as the night sky.

Several methods to determine a flatfield will be operational. However, each method suffers from different drawbacks. The various characterizations of the flat field, the **dome**, **twilight**, and

night sky flats, are specified under the **req.**542-545, while the eventual **master flatfield** to be applied to science and standard field observations, is constructed from a suitable combination of the dome, twilight and night sky flat fields (**req.**546).

Dome flats (**req.**542) are obtained by observing in **telescope screen park position** a fixed **domescreen** *relatively* uniformly illuminated by the **calibration lamp** with a stabilizing power supply. The illumination is not sufficiently uniform to measure large scale variations, and the color is very different from the night sky.

Twilight flats (**req.**543) are based on a bright, uniform source of illumination (twilight sky), that is unfortunately not of constant brightness and color. Unfortunately the 'twilight gradient' precludes measurement of the largest scale gain variation. Also bright objects may be visible even at twilight, which provides an additional complication.

Night sky flats (**req.**544), obtained by combining a large number of science observations, most closely mimic the illumination properties of the science frames themselves. These are the only flatfields usable for measuring the largest scale gain variations. Unfortunately, the assumption that the illumination is uniform (except for astronomical sources of course), has proven to be invalid on WFI (e.g Manfroid et al, 2000). It remains to be seen how large this problem of "sky concentration" will be for **OmegaCAM**. Computing the night sky flat is also a computationally expensive process, both because of the large numbers of frames involved, and because the need for a proper masking of bright objects in the field. Fortunately, this measurement may also be usable for the fringe correction.

The master flatfield (**req.**546), to be applied to science and standard field observations, is constructed from a suitable combination of the dome, twilight and night sky flat.

The approximation that the pixel-to-pixel variation in the gain is independent of wavelength is in fact incorrect. Interference effects, mainly in the filters and thinned silicon layers of the CCDs, introduce wavelength dependent gain variations that vary on small angular scales. Since most sources are continuum sources, and only the convolution $\int g(\lambda)I(\lambda)d\lambda$ is measured, this effect can be ignored when measuring source fluxes. However, due to variable strength of several sky lines, mostly apparent at the long wavelengths, the background will exhibit so-called **fringing** patterns, which can change during the night. This requires an additional calibration step for bands redward of R: the construction of suitable fringed background images (**req.**545).

The weight map is an important auxiliary file, which is used in several image processing steps. The weight map is intimately linked to the flatfields and therefore its construction is also addressed in this section.

Whenever individual pixels are combined, either in constructing source lists necessary for photometric and astrometric calibration, or in the coaddition of different frames, the **OmegaCAM**-reduction pipeline uses variance weighting (weight$= 1/\sigma^2$). The inverse variances are recorded in **weight maps**, which are computed as part of the image pipeline (ref. **seq.– 633)**

The debiased images record $S(x,y)$ counts in pixel x,y, that are related to the photon flux $I(x,y)$ by:

$S(x,y) = Gg_{DQE}g_{ff}(x,y)I(x,y)$,
Since photon shot-noise is much larger than the read-out noise, the rms-noise in the raw data is given by:
$\sigma_S(x,y) = G(g_{DQE}g_{ff}(x,y)I(x,y))^{1/2} = (GS(x,y))^{1/2}$.
Once data has been flatfielded ($S' = S/g_{ff}$), the counts are given by:
$S'(x,y) = Gg_{DQE}I(x,y)$,
and the rms-noise by:
$\sigma_{S'}(x,y) = G(g_{DQE}g_{ff}(x,y)I(x,y))^{1/2})/g_{ff} = (GS'(x,y)/g_{ff})^{1/2}$
The photon flux $I(x,y)$ is a sum of a uniform background I_{back} plus sources $I_{src}(x,y)$. Since, the surface brightness of the sky is (much) larger than the surface brightness of most sources, the rms-noise is given by:
$\sigma_{S'}(x,y) = G[g_{DQE}I_{back}/g_{ff}(x,y)]^{1/2} = (GS'_{back}/g_{ff})^{1/2}$
Hence, the rms-noise in an image is the product of a factor ($(GS'_{back})^{1/2}$) that is constant over one image, but will vary between images, and a factor ($g_{ff}^{-1/2}$), the inverse of the square-root of the flatfield, which varies over the image.

To account for image defects the **weight map** will give bad pixels a weight of zero. Bad pixels include hot (**req.**522) and cold (**req.**535) pixels, as well as pixels affected by saturation, cosmic rays and satellite tracks, as determined in **seq.– 633.**

5.4.1 Req. — *Bias - doit*

Objective:

Determine master bias frame.
The signal in raw scientific frames contains a component that is due to a bias current. This component shows up as an offset to the signal. The bias-offset has the following characteristics: i) the bias level grows to its asymptotic level in the first few hundred lines, and ii) the bias level depends on the total signal in a given line. Therefore, an initial bias correction—the **overscan correction**, is applied by averaging the overscan pixels for each line, and subtracting this value from that line.
In addition, the bias offset exhibits a residual pattern, which is measured by the master bias frame. To construct the master bias a series of 10 zero-second bias exposures is overscan-corrected, and then averaged, rejecting 5σ outliers ($\sigma =$ dispersion of the 10 bias exposures of individual pixels), due to particle hits during read-out. The resulting master bias frames will be used for the correction of all frames. For each master bias frame the mean value for each CCD chip will be determined and evaluated in a trend analysis.
As the readout noise dominates the rms scatter in the bias frames, while the shotnoise of the sky background dominates the rms scatter on the sky images, which is nominally much larger than the readout noise, it is sufficient to characterize the bias value at individual pixels with an accuracy of (readout noise/$\sqrt{10}$).

A comparison with a previous master bias frame will be done as an evaluation of the overall health of the instrument and the quality of the data. This will thus measure short-term variations. Long term variations can be assessed using trend analysis.
A comparison of the mean level with laboratory values will be used as an overall quality check.

Fulfilling or fulfilled by:

Selfstanding. Raw data are also used for **req. 522** *Bad/hot pixels*
Calfiles used by: **req. 542** *Dome flat*, **req. 543** *Twilight flat* **req. 544** *Night sky flat* **seq. 632** *Trim, de-bias, flatfield*

Sources, observations, instrument configurations:

10 observations with 0 (zero) seconds exposure time.

Required accuracy, constraints:

The required accuracy per pixel in the master bias frame is "nominal read-outnoise/$\sqrt{10}$".
For the quality check: Since an overscan correction is performed, the deviation of the mean level of master bias (bias level) from zero, should be less than TBD.

When performed/frequency:

daytime- Commissioning, in RP initially daily. Later the frequency is to be determined by experience.

Estimated time needed:

Observation: 15 min. Reduction: $<$ 2 min./CCD.

Inputs:

Raw data bias frames
CalFile– 541 *Master Bias frame* previous versions
Laboratory values of bias levels.

Outputs:

CalFile– 541 *Master Bias frame* to be used by **seq. 632** *de-bias flat field*

TSF:

Mode– Stare N=10
TSF– OCM_img_cal_bias

5.4.2 Req. — *Flat-field - dome key bands + user bands - doit*

Objective:

Determine master dome flat frame for both **Keybands** and **Userbands**.

Master dome flats are obtained through an average with sigma rejection procedure on a stack of raw dome flats, intended to reduce photon shot noise, remove cosmic rays.
During the lifetime of **OmegaCAM** the dome flatfields shall be measured for the 4 keybands and the key-composite filter at least once/week. Thus at least within 3 days of the taking of science data a dome flatfield in the key passband will be available.

The sequence of master dome flatfields in the keybands, acquired over periods of months to years will be used to perform a trend analysis on the long term stability of the instrument and lamp which illuminates the dome flatfield. With the exception of the effects of the unstability of the lamp, this trend analysis is redundant with that obtained from both **req. 563** *Photometric Calibration - zeropoint key bands - doit* and that of **req. 562** *Photometric Calibration - monitoring*. Thus, by combining the results of these **req.**'s an accurate description of the behaviour of the lamp is feasible. The prediction of the behaviour of the lamp is a result, which will be used as an input for **req. 547** *Quick detector responsivity check*.

The dome flatfields will be used on an individual CCD chip level. The relative variations of the quantum efficiciency between individual CCD chips will be measured by **req. 563** *Photometric Calibration - zeropoint key bands - doit*.

The redundancy between various measurements of **req. 563** *Photometric Calibration - zeropoint key bands - doit* and **req. 542** *Master Domeflat* at keybands will be used to evaluate the relative chip-to-chip gain variations, and in due time, when advanced insight in this item is achieved, this knowledge might be used to further optimize observing scenarios.

The cross-calibration/handshaking of two lamp sets will be done during a transition period of about one week. During that week observations will be taken with both lamp sets. Template TSF–OCM_img_cal_domeflat has a parameter which one of the two lamp sets will be used It is anticipated that about every 3 months a new set will become operational. During this transition period of about a week both lamps sets will be observed sequentially. Also TSF-OCM_img_cal_quick can be used for the crosscalibration.

For the userbands the dome flatfield will only be taken in the period of the week that that particular passband has been used for science observations. No trend analysis will be done on the data taken in the User pass bands.

It will be checked whether the dome flatfields are reproducable and whether artifacts appear on the same pixels. This will also serve as a check on the reproducibility of the filter exchange mechanism.

Fulfilling or fulfilled by:

Selfstanding.

Output is used by:

req. 563 *Photometric Calibration - zeropoint key bands - doit*

req. 547 *Quick detector responsivity* through the characterization of the dome flat field lamp.

req. 546 *Master flatfield*

Sources, observations, instrument configurations:

Domeflats with the four keyfilters and the single key composite filter. 5 observations per filter, with approximately 20000 ADU. Adding 5 exposures of 20,000 counts satisfies the accuracy requirement. Each science/standard observation preferably has an associated domeflat observed within 3 days. About 4 dome flats will be measured per day. The calibration lamps will be used and during a transition period of about one week both sets will be used.

Required accuracy, constraints:

Accurately measuring pixel-to-pixel gain variations as small as 1%. Re-insertion of the filter shall not alter the flat field stucture by more than 0.3% (rms, measured over the full detector area).

When performed/frequency:

Daytime, daily. For the keybands the dome flatfields will be measured at least once/week. For the Userbands the dome flatfields will be measured at least within 3 days that the Userband has been used for science observations. When filters have been changed in the cassette the presence of dust and/or scratches might require new flat field exposures. During Comm. the reproducibility of the filter exchange mechanism will be checked.

Estimated time needed:

Observation: 10 min. Reduction: 3 min./CCD.

Inputs:

Raw dome flatfields
CalFile– 541 *Master Bias frame*
CalFile– 522 *Hot pixel map*
CalFile– 523 *Gain*
CalFile– 535 *Cold pixel map*

Outputs:

CalFile– 542 *Master Domeflat frame*
CalFile– 542L *Dome Lamp*

TSF:

Mode– Stare N=5
TSF– OCM_img_cal_domeflat

5.4.3 Req. — *Flat-field - twilight*

Objective:

Determine master twilightflat frame, using observations of the twilight sky.
Twilightflat observations will be attempted for each passband that is observed during that night. If insufficient twilight time is available then the twilightflat observations are taken preferably in the previous or subsequent night. In addition twilightflats of the 4 keybands will be taken at least once a week.
In order to minimize the spatial gradient in the sky brightness, the observations need to be made on the solar circle, i.e. the great circle through the zenith and the sun's position, at a zenith distance of about 20° in the solar antidirection. Preferably, the field of view does not include stars brighter than TBD magnitude.
Master twilight flats are obtained through an average with sigma rejection procedure on a stack of raw twilight flats, intended to remove any contamination (including stars) present on individual raw twilight flats and reduce photon shot noise.

Fulfilling or fulfilled by:

Selfstanding

Sources, observations, instrument configurations:

Twilightflat with 5 observations per filter at 'empty' sky, near 20° from zenith in solar anti-direction. It may be advisable to determine a standard target list of approximately 10-20 empty fields, equally spaced in right ascension, at 20° from zenith.

The telescope should be tracking. The maximum jitter offset allowed by the TSF should be used in order to be able to remove stars. Observations should approximate 20000 ADU. Exposure time should be based on skybrightness, typically it may vary from 0.1 sec to 300 sec, changing rapidly during the twilight period. No effects of shutter are expected.

If the tracker can be used as an exposure meter, the desired exposure level can be set directly. Alternatively one can use the Tyson and Gal formula (in template ?) for the variation of the twilight brightness with time, to keep the exposure level constant. In the latter case, a trend anaysis of twilightflat can be used to calibrate this formula.

Each science/standard observation preferably has an associated twilightflat observed within 2 days. We expect a total of 10 twilightflats to be observed during each twilight period.

Required accuracy, constraints:

Mean levels should be approximately 20000 ADU.

When performed/frequency:

Evening twilight.

An attempt will be made to observe twilightflats for all bands observed during the night. For all observed bands, twilightflats will be observed within a maximum of 2 nights. In addition, twilightflats for the keybands will be obtained at least once a week, irrespective of whether keybands were used for science observations during that week.

Estimated time needed:

Observation: in total 25 min./night. Reduction: 3 min./CCD.

Inputs:

Raw twilight flatfields
CalFile– 541 *Master Bias frame*
CalFile– 522 *Hot pixel map*
CalFile– 523 *Gain*
CalFile– 535 *Cold pixel map*

Outputs:

CalFile– 543 *Master Twilightflat frame*

TSF:

Mode– Jitter N=5
TSF– OCM_img_cal_skyflat
Use an appropriate (empty) field, exposure time determined by tracker CCD, or Tyson-Gal

formula.

5.4.4 Req. — *Flat-field - night sky*

Objective:

Create Night Sky flat frame.

The flatfield that most closely reproduces the actual gain variation of the science and standard observation, can be obtained by averaging a large number of *flat-fielded* science and standard observations, taking care of properly masking the contaminating objects. While such a night-sky flat (aka superflat) could, in principle, improve on the quality of the twilight flat, the procedure to obtain this flat can be computationally very expensive. On the other hand night-sky flats may also be suitable for fringe removal.
It remains to be seen to what extent the problem of sky concentration, i.e. nonuniform illumination due to stray light/reflection affects the quality of the night-sky flat.
Because these night-sky flats can only be obtained from actual observations, we cannot guarantee their availability for bands for which only standards were obtained. It is, therefore, not clear how routine building of the skyframes should be incorporated into our photometric calibration scheme.
A minimum of 5 images in a night in a given band is required to optimally fulfill this requirement. Images are stacked and a median average is calculated, intended to remove any non-systematic effects (objects, cosmic rays, satellite tracks, etc.).
Check reproducibility of artifacts on flat field images in order to inspect filter exchange mechanism reproducibility and flexure of telescope.

Fulfilling or fulfilled by:

Data reduction of raw data from science and photometric standard observations
The night sky flat is used in **req.**546 Master flat.

Sources, observations, instrument configurations:

Science and standard observations

Required accuracy, constraints:

This procedure would benefit from a prior detection and masking of bright objects. If no masks of bright objects are available, then a minimum of 15 frames should be included.

When performed/frequency:

daytime, daily (flexure, reproducibility during Comm)

Estimated time needed:

Observation: None. Reduction: 5 min./CCD/filter for 15 science frames.

Inputs:

Raw science images
CalFile– 541 *Master Bias frame*
CalFile– 546 *Master flatfield*

CalFile– 522 *Hot pixel map*
CalFile– 535 *Cold pixel map*

Outputs:

CalFile– 544 *Nightsky flat frame*

TSF:

Raw data of science and standard star observations in jitter and dither mode is used. Avoid using multiple exposures with the same pointing in Stare mode.

This procedure benefits from first flatfielding the data, and determining the night-sky flat as a modification of this flatfield. First de-bias the science/standard frames and apply the flats, then normalize the frames and build a median average frame.

5.4.5 Req. — *Flat-field - Fringing*

Objective:

Determine the fringe pattern of the background.

Fringing due to variable strength of several skylines, mostly apparent at the long wavelengths, requires a different approach to background subtraction. Normally, after flatfielding, the background can be expected to be flat over the entire image, and a median of the image, excluding 5σ outliers, would in principle be sufficient to subtract the background.

In images that suffer from fringing we have to deal with a background that is variable on small ($<< 1'$) scales within the image, and can not be distinguished from sources. The image itself can, therefore, not be used to determine the background. However, given the fact that most observations are taken in jitter or dither mode, the information of several images can be combined to determine a background. This average should include enough observations to properly exclude contamination from sources, and, because the standard jitter/dither patterns only include 5 pointings, one background computation per jitter/dither is probably not sufficiently accurate. On the other hand, because the fringing pattern may vary with time and telescope position, a straight mean (the supersky) over an entire nights worth of data may also not be usable.

A suitable strategy to construct a fringed background image, usable for subtraction, thereby removing the fringe pattern, remains to be determined. If the fringe pattern is stable over the night, a decomposition of the night-sky flat in an additive and multiplicative term is feasable. The assumption that the high-frequency spatial component in the night-sky flat are fringes, while the lowest frequency components represent gain variations has been used with reasonable success.

Fulfilling or fulfilled by:

Data reduction of science and photometric standard observations

Sources, observations, instrument configurations:

Use science and standard data to determine background

When performed/frequency:

Commissioning and when long wave science frames are taken.

Estimated time needed:

Observation: None. Reduction: 5 min./CCD/filter for 15 science frames.

Inputs:

Raw science images
CalFile– 541 *Master Bias frame*
CalFile– 546 *Master flatfield*
CalFile– 522 *Hot pixel map*
CalFile– 535 *Cold pixel map*

Outputs:

CalFile– 545 *ff-fringe*

TSF:

Use same data as for night sky flat (**req.**544)

5.4.6 Req. — *Flat-field - master flat and weight map*

Objective:

Determine the master flatfield, to be used to correct for the pixel-to-pixel gain variation in the raw image data.

Three different measures of the variation in the gain are available: the dome flat (**req.**542), the twilight flat (**req.**543) and the night-sky flat (**req.**544).

A suitable choice of the final master flatfield, based on a combination of one or more of these flatfields, will be implemented.

A method whereby the master dome flat is used to measure the pixel-to-pixel (small-scale) variation, and the master twilight flat is used to measure the large scale variation, would provide a first-order approximation of the master flatfield. These spatial frequencies are separated using a Fourier technique. Night-sky flats are created from raw science or standard data, flat-fielded with this master flatfield and can be used to improve the quality of the master flat.

This master flatfield could then be used to flatfield the science and standard images in the image pipeline.

Experience at FORS has shown that a suitable combination of twilight and night-sky flats provided the best determination of the gain variation.

The master flatfield is proportional to the inverse variance in the flatfielded data and can therefore be used to build a weight image. Individual weight images (**seq.– 633**) assign a weight of zero to bad pixels (**req.**522, **req.**535), saturated pixels, pixels that have a relative gain outside a user defined range, cosmic-ray events and satellite tracks.

Fulfilling or fulfilled by:

Additional data reduction of flat fields obtained by **req.**542 543 544.

When performed/frequency:

daytime, daily

Estimated time needed:

Observation: None. Reduction: 3 min./CCD.

Inputs:

CalFile– 522 *Hot pixel map*
CalFile– 535 *Cold pixel map*
CalFile– 542 *Master Domeflat frame*
CalFile– 543 *Master Twilightflat frame*
CalFile– 544 *Nightsky flat frame*

Outputs:

CalFile– 546 *Master flatfield*

The master flatfield is used in **seq. 632** *Trim, debias and flatfield* and **seq. 633** *Construct individual weights.*

5.4.7 Req. — *Quick detector responsivity check - doit*

Objective:

Quickly check the overall health in terms of responsivity by observing the dome screen with the composite filter.

Together with **req. 521** *Read-noise* this item forms the most important day-to-day health check. The expected lamp intensity is characterized in **req. 542** *Dome flat*. This measurement will lead to a go/non-conformance flag and day report. The results will have to be inspected on the site, as this is a daytime health check of the instrument.

Trend analysis on the raw data will be redundant with that of **req. 542** *Dome flat*.

The equivalent of this **req.** on the sky is provided by **req. 562** *Photometric Calibration - monitoring*

Fulfilling or fulfilled by:

Selfstanding

Sources, observations, instrument configurations:

Dome flat with composite key filter

Required accuracy, constraints:

1%

When performed/frequency:

Commissioning, daytime, every day of operations both during CP and RP.

Estimated time needed:

Observation: 3 min/day. Reduction: 1 min./CCD.

Inputs:

2 raw dome flatfields **CalFile– 541** *Master Bias frame* **CalFile– 542L** *Dome Lamp*

Outputs:

CalFile– 547 *Quick check* **CalFile– 547r** *Quick check - day report*

TSF:

Mode– Stare N=1
(**TSF– OCM_img_cal_domeflat,** N=1, filter= composite)
= **TSF– OCM_img_cal_quick**

5.4.8 Req. — *Illumination correction*

Objective:

Characterize the illumination correction.

The zeropoint is determined individually for each CCD in **req.** 563. The gain variation over individual chips is characterized by the twilight and sky flatfields (**req.** 543 and **req.** 544) under the assumption of an ideal flat illumination over the field of view. In practice this ideal flat illumination can be affected by stray light (sky concentration) and a correction for this effect has to be made.

An initial verification during commissioning whether this effect is indeed present will be obtained by quickly deriving many zeropoints for individual stars in a standard field (eg from the INT-La Palma preparatory programme). This technique, which is fully automatic, could also be used to quickly verify the effect during RP.

In case the effect is found to have an amplitude over a single chip larger than 1% , it has to be characterized using series of measurements of a standard field with 32 pointings, such as done in **req. 569** *Secondary Standards*.

The map that results from the (interactive) characterization of the illumination correction is used to make an illumination correction frame for every individual chip (**CalFile– 548**).

Fulfilling or fulfilled by:

Initial verification of effect during Commissioning : selfstanding
Characterization of the effect : additional data reduction of **req. 569** *Secondary Standards*

Sources, observations, instrument configurations:

Standard equatorial field

Required accuracy, constraints:

better than 1% for the amplitude over a single CCD.

When performed/frequency:

First verification of effect during early commissioning. Characterization at end of Commissioning. During RP, once/month to be determined by experience.

Estimated time needed:
Verification of effect during Commissioning : 0.5 hour.

Inputs:
The inputs for deriving the illumination correction frame:
CalFile– 548F *Illumination correction fit coefficients*
The name of the chip for which to derive the frame

The inputs for deriving a quick-fit to the effects of stray light (Category III recipe):
Fully calibrated image of a equatorial standard field
CalFile– 569E *Primary Standard stars*

Outputs:
The output from deriving the illumination correction frame:
CalFile– 548 *Illumination correction*
The output from a full, interactive characterization of the effects of stray light:
CalFile– 548F *Illumination correction fit coefficients*

5.5 Astrometric Calibration

The aim of the astrometric calibration is to accurately determine the projection matrix for converting pixel positions to sky coordinates. This will be done automatically in the data reduction pipeline.

For **Mode– SSO** N= the astrometric solution can be derived provided some observational limits, restricting the curvature of the stellar track, are met. When stellar tracks become more curved than the limits, all astrometric quality checks will have to be relaxed. All source positions will be derived using the first-order moments of the pixel distribution of the detected objects. The resulting positions, in such cases, will be the weighted averages of the stellar tracks and that of the (than not) moving targets. The exposure time limitation is defined by the curvature of the stellar tracks in the field, which should be less than 1% over the full track. Estimates for limitations on tracking for **OmegaCAM** are defined by requiring the curvature of the stellar tracks to be less than 0.1 FWHM of the PSF ($< 0''6$). Assuming tracking in Ra, a track length of less than 0.1 degree at any declination is allowed. For a track length of 0.2 degree only declinations between 0 and +/-20 deg or +/-70 to +/-90 deg are within the above limits. For the other modes there are no such restrictions.

The astrometric calibration can be derived using two fundamentally different methods.

The first, traditional, method is to derive the full projection matrix separately for each pointing, ignoring any detailed prior knowledge (apart from some rough initial estimates such as pointing, orientation and platescale). This method has great freedom and allows for instrument independent determination of the projection matrix. It can thus be used on a variety of instruments, but requires more input data elements to achieve an accuracy equal to that of the next method.

The second method allows for a separate determination—and use—of instrument specific characteristics of the geometry that do not change (much) among different pointings and the characteristics that do change with pointing. Fixed characteristics are, e.g., position of the chips relative to each other, the position of the rotator axis, the optical deformation at the position of the focal plane and perhaps pointing accuracy. Variable characteristics include items like the flexure of the telecope and its instrument. The latter items need to be determined for each pointing separately. This method can be robust and has less degrees of freedom facilitating accurate astrometry with a small amount of data points. It is, however, tightly fixed to the instrumental geometry. A geometric model must be obtained and associated parameter values must be determined before standard astrometric reduction can be done.

Both methods will make use of an astrometric reference catalog. Current catalogs have positional accuracies that are not extremely high on the scale of the field of view of **OmegaCAM**. To achieve higher positional accuracy within a given pointing set and to allow accurate co-addition without degrading the PSF the astrometric solution will make use of the overlap among the pointing set.

The methods can be applied both to the main camera CCD chips and to the guide CCDs, as the latter can be viewed as a auxiliary CCDs of the main camera.

The requirements outlined here determine the calibration data necessary to perform an astrometric solution using prior knowledge of instrument specific characteristics.

The algorithm for the derivation of the astrometric solution is detailed in Section 7.3, while its use is detailed in **seq.– 634.**

5.5.1 Req. — *Position of Camera in focal plane*

Objective:

Determine the position of the chips with respect to the optical axis of the telescope. This is part of the static astrometric calibration of the camera. It involves the determination of the chip position, scale, and orientation with respect to a perfect pixel plane. This has to be done with the ADC in and out.

This procedure produces the astrometric pre-solution, allowing for a determination of an approximate pixel scale, distance of the reference pixel with respect to the optical axis and location and rotation of each CCD on the detector plate. In fact, the expected pointing error and other a-priori positional offsets are expected to be small; hence the standard astrometric solution can already be obtained without a pre-solution. However, a first inspection and verification of the pre-solution is a task to initialize the system.

The parameters to be derived are obtained in the standard image pipeline astrometric calibration procedure. These are in turn communicated to the Instrument Software, which writes these values as Fits headers (e.g. CDELT(2x), CRPIX (2x), CDMATRIX (4x). These FITS header keywords are used in the image pipeline as pre-solution/input parameters for the automated astrometric calibration (**seq.– 634**).

Fulfilling or fulfilled by:

Selfstanding

Sources, observations, instrument configurations:

High object density (but unconfused) areas such as open clusters. Standard areas, possibly overlapping with standard star fields. All filters and the two optical configurations ADC in and out should be exercised.

Required accuracy, constraints:

Internal precision: 0.3 pixel. External precision limited by reference catalog

When performed/frequency:

Each mechanical change of the camera. Each user supplied filter, once a year. Commissioning.

Estimated time needed:

Observation : 2 hours

Inputs:

CalFile– in1 *Astrometrical reference catalogue*, e.g. US Naval,or GSC2

Outputs:

seq.– 634 Communicate relevant parameter values of FITS keywords to Instrument software.

TSF:

Mode– dither N=5

TSF– OCM_img_obs_dither,each filter, ADC In/Out

5.5.2 Req. — *Telescope Pointing*

Objective:

Verify the pointing and the offsetting of the telescope for both optical configurations (ADC in and out).

The pointing model is provided independent of the **OmegaCAM** S/W, but a verification of both the pointing and the offsetting accuracy is required.

Perform on-site spot checks of the pointing model. The data from the Guider CCD can be used for this.

Also in the data reduction pipeline, as a standard check in the astrometric solution, the pointing error is determined.

Fulfilling or fulfilled by:

Selfstanding.

Sources, observations, instrument configurations:

Standard field

Required accuracy, constraints:

1 arc second

When performed/frequency:

Commissioning, after each change of the pointing model, and to be determined by experience.

Estimated time needed:

10 min

Inputs:

Offset Guide CCD

Outputs:

Conformance flag.

TSF:

Stare mode, dither and jitter mode. In fact all observations can be used.

5.5.3 Req. — *Telescope and Field Rotator tracking*

Objective:

Verify that the rotator performs properly and simultaneously that the telescope is tracking correctly.

Up to Zenith distances of 60 degrees and wind speed of 18 m/s with a dynamical component of 30%, the free tracking of the telescope shall be better than 0.2 arcsec rms. With closed-loop autoguiding, the rms deviation shall not exceed 0.05 arcsec
Two kinds of image deformations will be inspected.
First, check at various telescope positions the global performance of the rotator plate which is driven by the pointing model. When the rotator plate is not performing optimal, the objects are *elongated* in a circular pattern (concentric rings) with the rotator plate axis at the center. This inspection is done using **req. 554** *PSF Anisotropy*.
Second, check for the tracking of the telescope to find functional dependency with telescope position. This is purely a verification. As an internal check, do this for each **OmegaCAM** observing mode. This inspection is also done using **req. 554** *PSF Anisotropy*. When the telescope is not tracking correctly the shapes of stellar objects are systematically elongated. The amount of elongation may not exceed a certain value, corresponding to the basic tracking requirements given above.
The offset information from the Guider CCD's is another element in the functional check. When offsets for guide stars are becoming too large, rotator plate errors or telescope tracking errors are apparent as different patterns of offsets during an exposure time.
Positional information on single objects can be determined at 0.02 arcsec rms. Thus for a minimum of 100 objects the rms deviation of 0.2 arcsec rms for open-loop tracking and 0.05 arcsec for closed-loop autoguiding is readily available. A series of short exposures will give at least such numbers of objects for analysis, but longer exposures can yield as many as 100.000 objects for analysis allowing a higher signal to noise ratio for the determination of rotator plate and tracking errors.
Rotator plate determination should be carried out near zenith to allow for the largest field rotation possible during an observation. For moderate exposure times of a few minutes the field rotation can be sufficient (several tens of degrees equals one tenth of a full rotation) to produce detectable errors to verify the required accuracy.

Fulfilling or fulfilled by:
Data reduction of standard science observations (allmost all will do).

Sources, observations, instrument configurations:
Most observations can be used.

Required accuracy, constraints:
VST requirements:
free tracking better than 0.2 arcsec r.m.s.
autoguiding tracking better 0.05 arcsec

When performed/frequency:
Commissioning, at each change of the pointing model, in RP to be determined by experience.
In CP check once with the ADC in and out.

Estimated time needed:
First method: 2 min, Second method: 0.01 sec.

Outputs:
Conformance flags
Source extraction files
Source extraction calfiles (configuration, parameters files)

5.5.4 Req. — *PSF Anisotropy*

Objective:
Determine the PSF anisotropy.
Detailed characterization of the Point Spread Function at various positions in the focal plane shall be provided. Monitor optical defects and possible variations in time. Do this for both optical configurations of the telescope, ADC in and out.

Fulfilling or fulfilled by:
Data reduction of observations of high density field, such as employed in **req.**551.

Sources, observations, instrument configurations:
High density fields observed with **Mode– Stare** N=1.

Required accuracy, constraints:
better than 1%

When performed/frequency:
Commissioning
Each optical change to the telescope,
Remount of the detector assembly. Once per three months.

Estimated time needed:
Few minutes per pointing. Reduction: < 3 min.

Inputs:
raw science images
or
processed science images

Outputs:
CalFile– 554 *PSF anisotropy*

TSF:
Mode– Stare N=1
TSF– OCM_img_obs_stare

5.5.5 Req. — *The astrometric solution for templates - doit*

5.5.6 Req. — *The astrometric solution for Guide CCD's*

Objective:
Perform astrometric solutions for the Guide CCD's and hand over the solution to the Instrument S/W for locating Guide stars.

Note, the Guide CCDs can be read out separately and 'stand alone'. For this task INS should stream the FITS images of the Guide CCD's to the hard disk.

Fulfilling or fulfilled by:

Selfstanding

Sources, observations, instrument configurations:

Special readout (manual command) of the Guide CCD's into FITS files

Required accuracy, constraints:

1 arcsec rms for the accuracy with respect to the external standard;
External precision is driven by the position reference catalog. This is in the case of the USNO-A2 catalog of the order 0.3" with possible systematic excursions to 1".

When performed/frequency:

Commissioning.

Estimated time needed:

The images used are the Guide CCD images. For this the exposure time of the Guide CCD needs to be comparable to the Science CCD to ensure enough (gt 40) stellar images for astrometric calibration. Total time during Comm is about 1 hour.

Inputs:

Reference position catalog (see A4)

Outputs:

CalFile– 556 *Guide CCD guide star signal and offset*
astrometry solutions inserted into the descriptors; handed over manually to instrument S/W responsible

5.6 Photometric Calibration

The basic requirement for the photometric calibration of the broad-band filters is to achieve an accuracy of better than 5% on the photometric scale in 'instrumental magnitudes' as assigned to the units of the resultant output image of the "image pipeline". The accuracy of the colour transformation terms of instrumental to standard systems should be better than 10% on the photometric scale.

In order to maintain this accuracy on a routine basis over years of operation, a set of requirements are specified in this section.

The descriptions of these requirements involve the following **OmegaCAM** specific ingredients:

- **key passbands** ($X =$ u', g', r' and i' in Sloan system)
- **two lens correctors** (near Zenith, the baseline, key configuration) and an **atmospheric dispersion corrector -ADC** for operations in User mode at larger Zenith angles.
- a **composite key filter** ($X =$ u', g', r' and i' in each quadrant),
- a standard **polar field**, observable throughout the year,
- **8 equatorial fields**, containing both primary and secondary standard stars (Landolt fields - see section 7.1)
- a **dome lamp** and a **fixed dome screen** equipped with a stabilized current supply,
- **32 CCD's** are operated simultaneously, with the exception of the composite filter which 'feeds' 8 CCDs simultaneously in one passband.
- data rates should stay within limits that allow processing and storing of the data with the currently anticipated technology.
- A **standard atmospheric extinction curve** is adopted and all atmospheric extinction in various passbands is taken as a scaling of this curve.
- The photometric monitoring employs observing **strategy – freq** which has overriding priority on the scheduling and which employs observing **mode – stare** and its associated **trend analysis**.

The prime concept of the **OmegaCAM** photometric calibration is to *continuously* maintain the photometric scale in the keybands, even when the science programme does not require the usage of these passbands during a particular night or period. This continuity is used by the data reduction (calibration and its trend analysis) and is meant to ease the maintenance of the photometric system on a routine basis.

The usage of a standard extinction curve results into a high rigidity of the pipeline processing, and provides a tool for error estimates, quality checks, recognizing non-conform data and provides a framework for successful pipeline processing of incomplete data.

We model the characterization of the photometric system in terms of a series of gains, where for each aspect of the calibration we distinguish a gain g_0 at a pre-determined fixed moment and the variation of that gain as function of time $g(t)$, the latter being mostly analyzed by a **trend analysis**.

All photometry is determined on an individual CCD chip basis ($N =$ number of chip, 1...32), apart from the atmospheric extinction which is common for all chips.

Most gains depend on passband (X), but not the variation of the atmospheric extinction, which is assumed to scale with the standard extinction curve.

In Figure 5.6 an overview is sketched of the various requirements which form the photometric calibration.

The fixed and variable gains of the various calibrations are defined as follows:

Atmospheric extinction: use scaling of standard extinction curve represented by $g_{sel.e}(X)$:
middle of the night: $g_e(0) \times g_{sel.e}(X)$ **req.**563
during the night : $g_e(t)$, t in hours **req.**562

Zeropoint effective DQE - **req.**563
middle of the night: $g_{DQE}(0, N, X)$
on different nights: $g_{DQE}(t, N, X)$, t in nights

Flat field - **req.**542 and others
for period of 7 days: $g_{ff}(week, N, X)$
different weeks: $g_{ff}(t, N, X)$ t in weeks ; every week a new ff is assigned, replacing $g_{ff}(week, N, X)$

For a given star observed in passband X at a given position in the field of view, at a given moment (t) the relation between the output (I_{obs} of the detectors) and the zero-airmass intensity $I_{ref,X}$ is given by the general expression:

$$I_{obs,X} = g_e(0)g_e(t)g_{sel.e}(X) \times g_{dqe}(0, N, X)g_{dqe}(t, N, X) \times g_{ff}(week, N, X) \times I_{ref,X}$$

Colour term:
The primary standard stars have been measured with presumably the same filter passbands, but with CCD detectors which have a different relative spectral responsivity. This implies that the effective $g_{DQE}(0, N, X)$ when observing these primary stars depends on the colour of these stars: $g_{DQE}(0, N, X, X - x)$.

The photometric calibration involves the solution of the general equation above along a different path, with different unknowns, and different knowns.

The initialization of photometric calibration is to carefully process backwards and forwards through the basic equation. Particularly the settling of the secondary standards, which cover a larger field of view than the primary standards is tricky. On one hand the preparatory programme will provide this information, on the other hand **OmegaCAM** calibrations can self-calibrate the secondary standards, which has the advantage that it avoids the extra bootstrapping via another telescope and detector system.

Normalizations:
$g_{ff}(week, N)$ unity at central pixel of each chip N
$g_e(0)$ and $g_e(t)$ multiplication factor of standard extinction curve represented by $g_{sel.e}(X)$

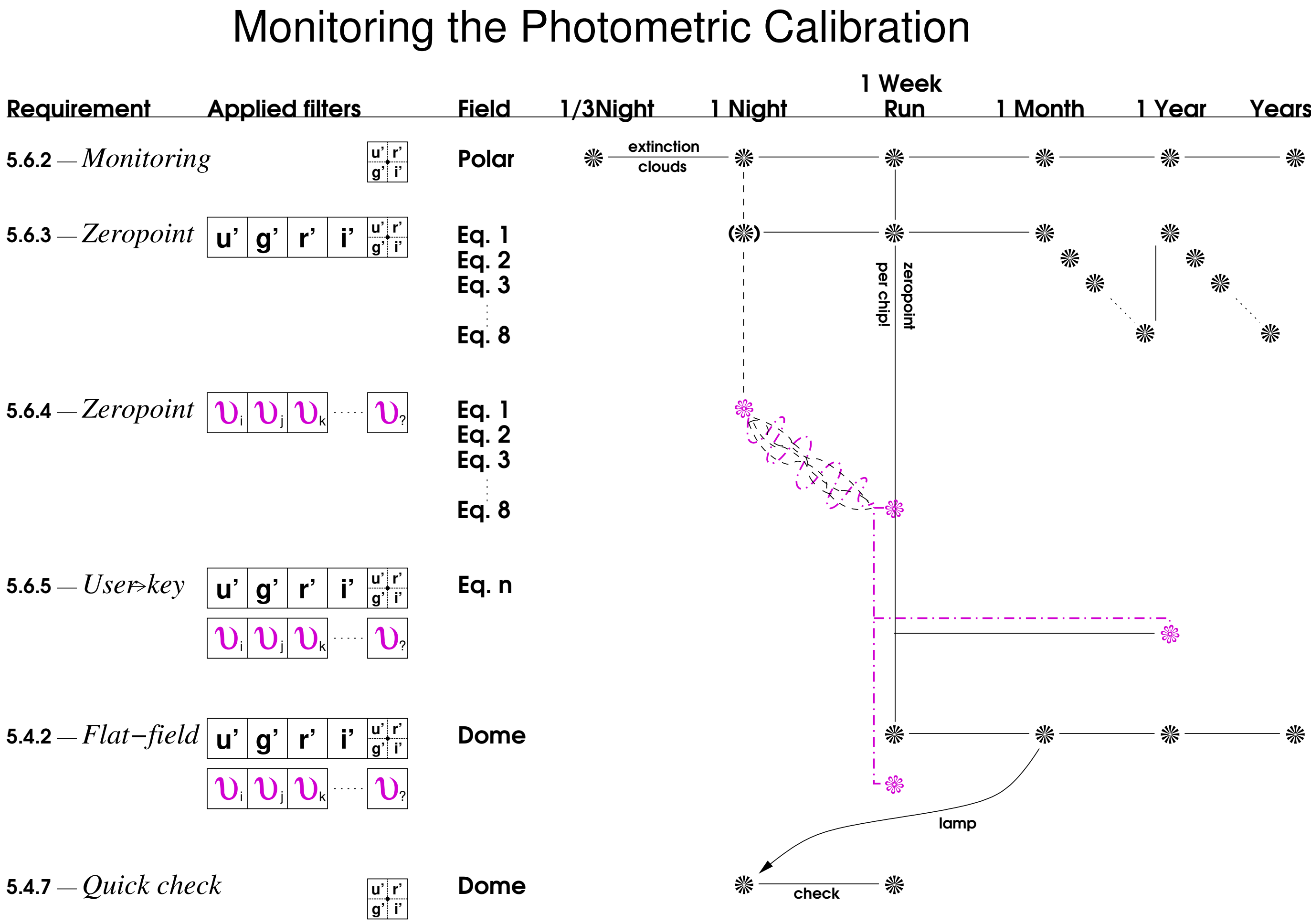

Fig 5.6. *Overview of tracking the photometric calibration at various time scales. From left to right, the figure indicates the requirement number, the requirement name, the used filters and standard fields. The stars indicate at which frequency the measurement is done. For further details, see text.*

5.6.1 Req. — *Shutter Timing*

Objective:

Verify the actual timing of the shutter, monitor position dependent delays of the shutter motion in both directions.
Exposure timing has to be accurate to $\pm 0.2\%$ at 1 sec exposure time at any position of the focal plane (**OmegaCAM** Technical Specifications). The exposure timing signal is provided by PULPO. For the following considerations we assume that the PULPO timing signal is accurate to better than 0.1 msec (i.e. it is not the dominating source of inaccuracy).
The shutter mechanism consists of a pair of chasing carbon fibre blades. Their movement is controlled by the Shutter Control Unit (Shutter CU) such that it results in an identical effective exposure time all over the frame. These two movements may or may not overlap in time depending on the exposure time and the blade traveling time.
The opening blade starts moving immediately (μsec's) after the falling edge of the TTL signal (provided by PULPO). This is the beginning of the exposure procedure. The closing blade starts moving immediately (μsec's) after the rising edge signal was detected and ends (about 1 sec later) when the closing blade completely covers the aperture, which marks the end of the exposure procedure. Therefore, the duration of an exposure procedure is always:
`exposure time + blade travel time (ca. 1 sec)`
Two types of delays affect the effective exposure time: The delays of the start of the blade movements after the opening/closing TTL signal edge (i.e. absolute exposure time) and position dependent delays during blade movement (i.e. exposure homogeneity).
The open/close delays are up to 0.05 msecs due to signal polling of the Shutter Control Unit software. These values are well within the requirements (shutter open time error: $\pm 0.2\%$ at 1 sec corresponding to ± 2 msecs). Deviations from this occur only in case of a severe shutter failure which is detected by the Shutter CU and PULPO independently followed by operator actions.
Position dependent delays (requirement: 0.2% at 1 sec exposure time) will be monitored in regular intervals of 3 months. This will be done for both shutter movement directions.
Dome flatfields of 10 sec and 0.1 sec exposure time will be taken for both shutter blade movement directions. Illumination level shall be such that the CCD's are at about 60% to 80% full well for the 10 sec exposure. Exposure times will have to be evaluated during Commissioning.

Fulfilling or fulfilled by:

selfstanding

Sources, observations, instrument configurations:

Dome flat field with a level of about 40,000 - 50,000 ADU's

Required accuracy, constraints:

Timing error less than 0.2%.

When performed/frequency:

Commissioning, once per 3 month, further to determined by experience. Daytime

Estimated time needed:

1 hour

Inputs:

Raw dome flatfields
CalFile– 541 *Master Bias frame*

TSF:

Mode– Stare N=4
(**TSF– OCM_img_cal_domeflat,** $N = 4$, $t_{exp} = 10.0, 0.1, 0.1, 10.0$)
= **TSF– OCM_img_cal_shutter**

5.6.2 Req. — *Photometric Calibration - monitoring*

Objective:

Monitor any **short term** variability related to the transparency of the atmosphere (atmospheric extinction) or due to instrumental instabilities (e.g. effective DQE) with a minimum sampling of at least 3 times/night. This provides a **daily overall health check** of the instrument and detectors. A further trend analysis has to provide information on **long term** stability.

The variation (r.m.s.) of the flux detected by the autoguider shall also be used as an indicator (put in the FITS header) of the sky conditions. This is to be done for each science observation.

This monitoring is done on a standard **polar field**, which will be repeatedly observed at the beginning, middle and end of the night with the **composite key filter** (u', g', r' and i' band), irrespective of the passbands used for the science observations. The observations are done in the standard configuration, with the two-lens corrector. A comparison of the measured intensity of the stars with reference values is used to qualify the overal conditions of instrument and atmosphere, the actual zeropoint (both unit airmass extinction and instrument DQE) being determined by **req.**563.

The comparison of the observed signal with the expected signal from standard stars in each of the four quadrants will lead to the determination of the product of the atmospheric extinction and the overall effective DQE of the detector system including the optics, i.e. $g_e(t) \times g_e(0) \times g_{st.e}(X) \times g_{DQE}$, with $g_{st.e}(X)$ the gain of the standard extinction curve at passband X, and g_{DQE} the overall effective DQE. As **req.**563 solves for g_{DQE}, a comparison with these measures gives $g_e(t) \times g_e(0) \times g_{st.e}(X)$, the variation of the gain during the night. The thus derived values of $g_e(t) \times g_e(0) \times g_{st.e}(X)$ at $t =$ beginning, middle, and end of the night (could be more if the observer so wishes) provides the required monitoring. Note that in this scheme, $g_e(t) = 1$ by definition for the middle of the night ($t = 0$). Excursions from the standard extinction curve due to extraordinary meteorological conditions, can be traced by computing the standard deviation of observed minus standard curve values in the various bands.

The repetitive measurements on the same field and with the same filter will also be used in trend analysis to monitor the overall long term stability of the instrumentation and atmosphere. The redundancy of these measurements with **req. 563** *zeropoint* and **req. 542** *Flat field -dome* will be used as a cross-check on the validity of the photometric system.
The data taken through the composite filter will provide a simultaneous measurement of the sky brightness in the four different **key bands**; this data will thus give a spectrum of the sky with a resolution R of roughly 5. This sky spectrum shall be derived on-line from the data. This serves as a quality check on the health of the instrument and on the clearness of the atmosphere, as clouds or cirrus will be immediately noticable in the spectral shape. Reference tables containing the expected sky brightness (and thus colour) as function of lunar phase will be used in the evaluation of the data.
Note that small differences exist between the monolithic key-band filters and the composite filter (see **req. 565**). This might lead to small color terms that should be taken into account if needed.

Fulfilling or fulfilled by:
Selfstanding; a corresponding requirement on detector level is
req. 547 *Quick detector responsivity check-doit*

Sources, observations, instrument configurations:
The **OmegaCAM** polar field, key composite filter, two lens corrector; short (about 20 sec) integration **Strategy– freq**

Required accuracy, constraints:
all photometry better than 1-2% on the photometric scale.

When performed/frequency:
beginning, middle and end of each night; any moment atmospheric conditions are suspect.

Estimated time needed:
Observation: 3 times 4 min. (100 sec preset + 100 sec integration + 42 sec readout) totalling 12 min/night each night. Reduction: 10 min./CCD.

Detailed estimate of required integration time:
The secondary standard stars in the standard field have a limiting magnitude g'~ 20. The internal accuracy of the present task is set on 1-2% level in order to achieve an overall end-to-end accuracy of better than 5% on the photometric scale. Clearly, for the composite filter the desired exposure time will be dominated by the response in the u' band. Using the WFI2.2m ETC, corrected for the VST optics and estimated CCD spectral responsivity, we estimate a S/N= 20 after 100 sec integration for a V=20 F0V star at airmass 2 (South Pole) with nominal 1.0 arcsec seeing. Thus, most secondary standard stars will have a S/N better than 20 in the u' band in a 100 sec integration. This would just match to the wanted 5% overall photometric accuracy in the u' band, but would lead simultaneously to higher S/N in the other bands. We compute for a V=20 GoV star S/N=90 in i' new moon, S/N=70 in r' new moon, S/N=45 in r' full moon and S/N =80 in g' new moon. Thus an integration

time of 100 sec for the composite filter appears reasonable, but clearly the u' band data give lower photometric accuracy, and the final value will depend on the achieved responsivity in the u' band. The final number has to be determined by experience and depends on the distribution and colours of the stars in the u' quadrant of the field of view.

Inputs:

The inputs for deriving the photometry result tables are:
Fully calibrated image of the polar standard field
CalFile– 569 *Secondary Standard Catalog*
CalFile– 565C *composite -> monolithic*

The inputs for deriving the transparency of the atmosphere are (Category I recipe):
List of photometry result tables
CalFile– 563 *Zeropoint + extinction - keybands* (g_{DQE} and $g_e(0) \times g_{st.e}(X)$)
CalFile– 564E *Standard extinction curve*

The inputs for the **on-line** monitoring of the sky spectrum are (Category III recipe):
List of input raw images of the polar standard field
List of input masterbias frames
List of input masterflat frames
CalFile– 562Su *Sky brightness-u'* Reference values u'
CalFile– 562Sg *Sky brightness-g'* Reference values g'
CalFile– 562Sr *Sky brightness-r'* Reference values r'
CalFile– 562Si *Sky brightness-i'* Reference values i'

Outputs:

The output from deriving a photometry result table is:
CalFile– 562T *Photom + Sky*

The output from deriving the transparency of the atmosphere is:
CalFile– 562 *Extinction - night report* ($g_e(t) \times g_e(0) \times g_{st.e}(X)$ at var. t)

Series of output files will be used for trend analysis

TSF:

Strategy– freq
Mode– Stare N=1
(**TSF– OCM_img_obs_stare,**N=1, filter=composite)
= **TSF– OCM_img_obs_monit**

5.6.3 Req. — *Photometric Calibration - zeropoint key bands -doit*

Objective:

Determine the zeropoint of the overall detector chain, separately for each CCD chip, in all four keybands (no composite filter) and the true atmospheric extinction at midnight by measuring standard stars in the 4 key passbands in one of the eight equatorial fields and the polar field. Do this every night whatever the science programme on the telescope may be. Optionally, add one observation of another equatorial standard field with higher airmass to obtain a redundant, classical, measurement of the atmospheric extinction.

The keybands plus the two-lens corrector form the standard for this requirement, the use of the ADC is considered as User mode (see **req.**564).

The zeropoint corresponding to the DQE of each of the 32 CCD chips will be determined on an individual chip basis $g_{DQE}(0, N, X)$. Thus the composite filter can not be used for this. However, additional data will be acquired with the composite filter for redundancy. In case the relative gain variations of individual CCD chips appear small and well characterized by the overall flatfield (which is not really expected) then the **req.** might be fulfilled with only the composite filter, substantially releaving the data rate and workload.

The combination of the data of **req. 562** *Monitoring* taken at the middle of the night with the present zeropoint data will be used to solve separately for the effect of the extinction and DQE at the middle of the night. A standard extinction curve will be used as a reference, for error analysis, and to support the derivation of the solutions in the pipeline processing.

As **primary standards** the Landolt equatorial fields will be used, possibly extended with preparatory programme results (Section 7 of CP). For each of the 8 equatorial fields a solution for **secondary standard** stars will be made for a larger, one degree, field of view. The acquisition of catalogues of secondary standards is discussed in **req.**569. These secondary standards data will be used for the nightly determination of the zeropoint.

During commissioning the reproducibility of the zeropoint determination should be verified for the different observing modes **Mode– jitter** N=5 and **Mode– dither** N=5. This also serves as an end-to-end-test.

In the case that composite filter data is used for the analysis, the transformation between composite and monolithic key band filters should be taken into acount (see **req. 565** *Filter band passes*).

Fulfilling or fulfilled by:

selfstanding, but uses data of **req.**562 at the middle of the night.

Sources, observations, instrument configurations:

Strategy– freq Mode– Stare N=1 **OmegaCAM** equatorial fields; exposures in u', g', r' and i' and composite. Two lens corrector.

Required accuracy, constraints:

1% on the photometric scale

When performed/frequency:

Once in the middle of each night. The linking of external (primary) to internal (secondary) standards will be done once during commissioning, and the first year of operation for each standard field; after that to be determined by experience.

It is to be determined by experience (stability of the system) whether the nightly zeropoint measurements can be relaxed as follows: in case the keyfilters are not used for science observations in a particular night, it is sufficient to only take an exposure with the composite filter.

During commissioning the **Mode– dither** N= and **Mode– jitter** N= have to be verified.

Estimated time needed:

Observation: 12 min. each night Reduction: 3 min/CCD/filter.

Detailed estimate of required integration time:

The secondary standard stars in the standard fields have a limiting magnitude g'~ 20. The internal accuracy of the present task is set on the 2% level in order to achieve an overall end-to-end accuracy of better than 5% on the photometric scale. Given an airmass of 1.3 and an S/N=50, we expect an integration time of:

u' band 110 sec but S/N =45 for F0V
g' band 60 sec
r' band 75 sec
i' band 115 sec

As there will be many much brighter stars (than the g'=20 limiting mag for which this calculation is made) in the field of view, leading to much better S/N these integration times will be sufficient for the goals, also at other moonphases (actually checked with ETC). The u' band observations are on the limit and should be carefully checked during Commissioning. Thus a total sequence would last including readout of 42 sec:
preset (100), u'(110 + 42), g'(60 + 42) , r'(75 + 42), i' (115 + 42) = 628 sec

In addition, a composite filter image should be taken (100 sec) which in the long run might replace the u', g', r', i' sequence with monolithic filters.

Inputs:

In pipeline data reduction, the **req.**563 reductions of a given night should preceed the **req. 562** *Monitoring* reductions.

The inputs for deriving the photometry result tables are:
Fully calibrated image of equatorial standard field
CalFile– 569 *Secondary Standard Catalog*

The inputs for deriving the zeropoints for the night are:
List of photometry result tables
CalFile– 562 *Extinction night report*
CalFile– 564E *Standard extinction curve*

Outputs:

The output from deriving a photometry result table is the same as for **req.** 562.

The outputs from deriving the zeropoints for the night are:
CalFile– 563 *Zeropoint + extinction - keybands* (always) used by **seq.– 636.**

TSF:

Strategy– freq
Mode– Stare N=1
(**TSF– OCM_img_obs_stare,** N=1, filter=key band)
= **TSF– OCM_img_obs_zpkey**

5.6.4 Req. — *Photometric Calibration - zeropoint user bands*

Objective:

Determine the zeropoint of the overall detector chain and the atmosphere by measuring standard stars in the **User passbands**.

The zeropoints of the photometric calibration in the User bands will only be determined for the nights that the User bands are actually used for scientific observations. The measurements will be done on one of the eight equatorial fields.

The atmospheric extinction will be determined in the keybands through **req. 562** *monitoring* on the polar field. The extinction results from **req. 562** *monitoring* are appended here, like in **req.**563, with a monolithic exposure at the equatorial field at midnight. The extinction curve will be used to transform the measured atmospheric extinction at the keybands to the User bands.

The transformation (colour term) of the user passband to the key passbands is determined for a limited set of filters and the ADC with the keybands in **req.**565.

By combining the extinction results in the keybands, the passband transformation coefficients and the direct zeropoint measurements in the User bands, the zeropoint corresponding to the DQE of each of the 32 CCD chips will be determined on an individual chip basis.

Trend analysis on these data is not required. The instrumental magnitudes of standard stars in each of the userbands will not be solved.

Fulfilling or fulfilled by:

Selfstanding, but uses data of **req.**562 at the middle of the night.

Sources, observations, instrument configurations:

All observations done with **Mode– Stare** N=1. **OmegaCAM** equatorial fields; always one exposure in composite key filter and additional exposures in User bands.

Required accuracy, constraints:
2% on the photometric scale for broad bands and 5% for narrow band filters.

When performed/frequency:
Once in the middle of each night.

Estimated time needed:
2-3 minutes per User band. Reduction: 3 min./CCD/filter.

Inputs:
The inputs for deriving the photometry result tables are:
Fully calibrated image of equatorial standard field
CalFile– 569 *Secondary Standard Catalog*
CalFile– 565 *User -> key*
The inputs for deriving the zeropoints for the night are:
List of photometry result tables
CalFile– 562 *Extinction night report*
CalFile– 564E *Standard extinction curve*

Outputs:
The output from deriving a photometry result table is the same as for **req.** 562.

The outputs from deriving the zeropoints for the night are:
CalFile– 564 *Zeropoint - extinction - Userbands* (always)

TSF:
Mode– Stare N=1
(**TSF– OCM_img_obs_stare,** N=1, filter=userband)
= **TSF– OCM_img_obs_zpuser**

5.6.5 Req. — *Filter band passes - user bands vs key bands*

Objective:
Characterize the transformation coefficients, including the colour term for the **OmegaCAM** user passbands to the **OmegaCAM** key passband.

In addition, determine the expected small colour terms between the four bands of the *composite* filter and the *monolithic* filters for all the **key bands**. The monolithic filters for the key bands are produced by a different company than the composite filter. The colour terms of the transformation monolithic-composite filter are put in a Calfile which is used as input in the determination of the zeropoint of the night **req.**563.

The standard keybands are calibrated in **req.**563 with the two lens corrector; the characterization of the ADC at the keybands and its transformation to the standard configuration is part of the present requirement.

Fulfilling or fulfilled by:
Selfstanding.

Sources, observations, instrument configurations:
OmegaCAM equatorial fields; **Mode– Stare** N=1; ADC for key passbands.

Required accuracy, constraints:
10% on the photometric scale (formal spec) and 2% (goal) for broad band filters
1% for composite -> key

When performed/frequency:
Once commissioning for user bands, once/year for composite filter

Estimated time needed:
20 min/run

Inputs:
Reference magnitudes and transformations:
CalFile– 569 *Secondary Standard Catalog*
CalFile– 564E *Standard extinction curve*

each night:
CalFile– 562 *Extinction night report*

Outputs:
CalFile– 565 *User -> key - monolithic*
CalFile– 565C *composite -> monolithic*

5.6.6 Req. — *Dependency on angle - ADC, rotator/ reproducability*

Objective:
Verify the dependency of the photometric calibration on the angle of the field rotator.
Measure dome flatfield at 12 field rotator angles.
Measure the polar field with 12 field rotator angles.
This also verifies the reproducibility and provides an end-to-end test.

Fulfilling or fulfilled by:
Selfstanding

Sources, observations, instrument configurations:
Flat field on dome with the 4 key passbands.

Required accuracy, constraints:
1% on the photometric scale

When performed/frequency:
Commissioning

Estimated time needed:
Dome: day time, one day
polar field 6 hours.

Outputs:

Flat fields - internal

TSF:

Mode– Stare N=12
TSF– OCM_img_cal_domeflat
and
Mode– Stare N=12
TSF– OCM_img_obs_stare

5.6.7 Req. — *Linearity (as a function of flux)*

Objective:

Verify the linearity (ratio of input over output) of the overall detector amplification- data reduction chain for the three different observing modes as an end-to-end test.

Compare the resultant magnitudes derived by the image pipeline by taking short and long exposures of the same standard field.

Fulfilling or fulfilled by:

Selfstanding

Sources, observations, instrument configurations:

Equatorial field in all the four key passbands; short 10 sec, 100 sec, 400 sec and 800 sec exposure. Two lens corrector.

Required accuracy, constraints:

Better than 1% on the photometric scale

When performed/frequency:

Commissioning

Estimated time needed:

Commissioning 6 hour

Outputs:

OK flag

TSF:

Mode– Stare N=2
TSF– OCM_img_obs_stare
and
Mode– jitter N=5
TSF– OCM_img_obs_jitter
and
Mode– dither N=5
TSF– OCM_img_obs_dither

5.6.8 Req. — *Detection limit and ETC calibrations*

Objective:

Verify the effective detection limit/ overall througput of VST + camera and subsequently the parameter values used for the Exposure Time Calculator.

Fulfilling or fulfilled by:

Data analysis of **req. 563** *Zeropoint*, **req. 567** *Linearity end-to-end-test*

Required accuracy, constraints:

10 % in detection limit

When performed/frequency:

Commissioning

Outputs:

Values for ETC

5.6.9 Req. — *Secondary Standards*

Objective:

Build catalogs of secondary photometric standards by observing Landolt fields, centered on each individual CCD.

A fundamental concept in the calibration of **OmegaCAM** data is the photometric calibration for each separate CCD. To obtain this calibration with a single observation requires photometric standards covering the entire FoV of the instrument. There are currently no catalogs of photometric standard stars satisfying this requirement. Hence, obtaining such catalogs of **secondary standards** for the equatorial fields and the polar field will be part of the calibration observations to be performed during operations.

Obtaining the necessary observations of secondary standards is a time-consuming operation (see below). Moreover, because these observations should cover all 8 equatorial fields (ref **seq.– 563),**approximately two (bright) nights each month will have to be reserved for these observations, at least in the first year of operations.

The set of secondary standards observations will also be used to determine the illumination correction (**req.**548). Note, that this constitutes a bootstrap problem, because determining accurate zeropoints of the secondary standards requires that the illumination correction is already known.

Because of this bootstrap problem, a straightforward determination of the zeropoint requires that for each CCD the zeropoint and illumination correction are determined simultaneously using primary standards. Therefore, obtaining measurements of secondary standards requires a sequence of observations that positions the primary standards in each CCD, i.e. 32 pointings per field, per filter.

An initial determination of the illumination correction will serve as a check on the magnitude of the effects of stray light. To do this in a quick and efficient way, a preliminary catalog of standard stars that cover the FoV of **OmegaCAM** is required. The data for constructing such

a catalog (**CalFile– 569E**) has been obtained. In case the effects of stray light turn out not to be negligible, the illumination correction will have to be characterized (see **req.** 548).
The order of priority of determining standards is first the **key bands** followed by the composite filter.

Fulfilling or fulfilled by:
Selfstanding.
Initial determination of the illumination correction is used to verify presence/absence of this effect (see **req.**548).

Sources, observations, instrument configurations:
Strategy– freq Mode– Stare N=1 **OmegaCAM** equatorial fields and polar field.

Required accuracy, constraints:
0.02 mag in individual secondary standards stars. The sources in **CalFile– 569** should cover a FoV of approximately 1.2 square degree.

When performed/frequency:
Commissioning, 2 nights of bright time, each month in the first year.

Estimated time needed:
Two standard fields are observed each month, with an observing time of 5.8h each. Each standard field is observed with 32 pointings, in each of the **key bands**. Using an observing strategy in which the filter is changed after every set of 32 pointings, the total observing time T_{obs} for one field is estimated by:

$$T_{obs} = \sum_{i=1}^{N_{filter}} [(T_{int}(X_i) + T_{read} + T_{mov}) \times 32 + T_{filter}],$$

with $T_{int}(X_i)$ the integration time in band X_i, T_{read} the readout time of the full detector block, T_{mov} the movement time of the telescope, and T_{filter} the filter exchange time.
With a T_{read}=25s, a T_{mov}=40s, and a T_{filter}=75s, the total integration time for the four **key bands** and one field will be ≈ 21000s (5.8h). The integration times for each of the four **key bands** are: $T_{int}(u')$=110s, $T_{int}(g')$=60s, $T_{int}(r')$=75s, $T_{int}(i')$=115s. The reduction time of the data taken for one field is 2 hours per CCD/filter.

Inputs:
CalFile– 569E *Primary Standard stars*

Outputs:
CalFile– 569 *Secondary Standard Catalog*
CalFile– 548 *Illumination Correction*

TSF:
Strategy– mosaic
Mode– Stare N=1
TSF– OCM_img_obs_stare

5.7 Internal alignments, optics etc

5.7.1 Req. — *Camera focus/tilt*

Objective:

Determine and verify the camera focus.

In a series of exposures both M2 will be moved and charge will be moved over a single chip, so that only one read-out is nessecary (TS 3.3.12).

Verify once for each filter that they have the same optical thickness (15mm physical thickness). Do this by measuring the "filter focus offset".

The tilt of the detector plane with respect to the focal plane and its dependency on the orientation of the telescope shall be determined both from:

CalFile– 554 *PSF anisotropy*

and from the matrix of best focus positions provided by the present requirement.

Fulfilling or fulfilled by:

Selfstanding

When performed/frequency:

verify focus: CP and RP. Filter thickness and tilt only once during comissioning.

Estimated time needed:

Observation:
- Focus offset and tilt: 2 hours during CP
- Verification filter focus offset 10-30 min/filter (Commissioning)

Reduction: 1 min/CCD.

Outputs:

for filter offsets:
-focus offset values to be transferred to INS data base
-Conformance flag for optical thickness of all filters

For tilt during CP:
-Tilt value

TSF:

TSF– OCM_img_tec_focusseqwhich stores data for one chip. For the special occasion of the tilt determination data of all chips will be stored (a trivial mod).

5.7.2 Req. — *Ghosts - ADC*

Objective:

Verify the absence/presence of ghosts.

For each available filter inspect the presence of ghosts by making several exposures near a very bright star at various angular distances from the field center. Do this for both correctors.

Various studies on expected behavour of ghosts are posted on **OmegaCAM**website. Bottom line of these studies is that ghosts are expected to be very faint and very large, pre-cluding their suppresion by dithered observations and subsequent masking.
The inspection will be done in first instance visually on the RTD.
Off-line the images will be fed to the standard pipeline for closer inspections.

Fulfilling or fulfilled by:
Selfstanding

Sources, observations, instrument configurations:
Very bright star at several angular distances from the field center (0.7, 1, 2, 3 degree, to be determined by experience). All available filters, or when a new filter is installed.
To be done for both correctors, to be determined by experience.

Required accuracy, constraints:

When performed/frequency:
CP

Estimated time needed:
1 hour/filter

TSF:
Mode– Stare N=1
TSF– OCM_img_obs_stare

5.8 Effect of Telescope

The various effects of the telescope on the quality of the images produced by the camera have been addressed by the following **req.**'s:

req. 524 *Electromagnetic compatibility*
req. 551 *Position of camera in focal plane*
req. 552 *Telescope pointing*
req. 553 *Telescope and rotator tracking*
req. 554 *PSF anisotropy*
req. 566 *Dependency on rotation angle - field rotator, ADC*
req. 572 *Ghosts*

This list appears rather complete and no additional requirements are specified.

5.9 Workhorses and End to end tests

WORKHORSES

The following 'work horses' or 'doit' requirements are specified:

req. 521 *CCD read noise - doit*
req. 531 *CCD Dark Current - doit*
req. 541 *Bias - doit*
req. 547 *Quick detector responsivity check - doit*
req. 555 *The astrometric solution for templates - doit*
req. 563 *Photometric Calibration - zeropoint keybands - doit*

The following **end-to-end tests** (i.e. observational data which employ many different aspects of the system and which can be used to trace reproducibility) have been specified:

req. 566 *Dependency on rotation angle - ADC, rotator/ reproducibility*
req. 567 *Linearity (as a function of flux)*
req. 562 *Photometric calibration - Monitoring/ Health check*

5.10 On-site quick look analysis

Requirements for the Real Time Display, essentially requirements on how to perform visual health checks on the acquired data, are given in the Instrument S/W User requirement document.

Here **req.**'s are listed which require analysis on the site.

The first list gives the requirements for which on-site analysis is essential (listed in order of priority).

req. 562 **Photometric calibration- Monitoring/ Skyspectrum*
req. 547 **Quick detector responsivity check - doit*
req. 521 **CCD read noise - doit*
req. 531 **CCD Dark Current - doit*

The second list gives the requirements for which on-site analysis is desirable/most practical (listed in order of priority). On-site, these activities will output go/no-go flags.

req. 571 *Camera focus/tilt*
req. 552 *Telescope pointing*
req. 553 *Telescope and rotator tracking*
req. 566 *Dependency on rotation angle - field rotator, ADC*
req. 524 *Electromagnetic compatibility*

req. 551 **Position of camera in focal plane*
req. 554 **PSF anisotropy*
req. 572 *Ghosts*

In the lists above the **req.**'s which produce a **CalFile–** are marked with a *. These **req.**'s have also to be processed off-line at ESO HQ (e.g. DFS pipeline, DFS operations, calibration pipeline, QC1, Quality control, trendanalysis).

DFS-pipeline modules, extracted from the off-line ESO HQ version, (including thosee used for calibration pipeline and QC1) could fulfill these task on-site with relative limited extra effort. Such modules will run with a stripped Calfile-date base As a desirable side effect, this creates the possibility to also quickly verify any other **req.**'s with extracted DFS-pipeline modules in the case of un-expected events.

The filling of the calibration database (**CalFile–)**should however be exclusively handled by the off-line pipeline at HQ.

6 DATA REDUCTION SPECIFICS- see URD and DRS

Baseline requirements are listed in the URD, specifications of implementations are given in the DRS.

7.0 PREPARATORY PROGRAMMES

The Consortium undertakes several preparatory progammes which support the general scientific requirements for **OmegaCAM**, but which do not form part of the deliverables as negociated in the MoU.

In the URD, some top level statements on these programmes are given, while details etc. are presented in the calibration plan.

ESO's Wide-field imaging at the 2.2m telescope at La Silla (WFI@2.2m) with the 8k × 8k camera will be used as a **test bed** for some applications and procedures of the **OmegaCAM** project. Unfortunately, ESO's DFS is only implemented in a very limited way for the WFI@2.2m, which limits this exercise. The **Preparatory photometric programme** (allocated at WFI@2.2m), meant to extend the photometric standards to a one square degree FOV, will be used to verify and finetune the calibration procedures (and requirements) for **OmegaCAM**.

Since the observing conditions during the WFI runs were not very good, and because of the different passbands of the WFI filters compared to **OmegaCAM**, the Consortium is running another campaign on the INT wide field imager at La Palma, extending the Landolt equatorial fields to one square degree. During 3 observing runs good observational data has been obtained, which will be processed by **OmegaCAM** prototype pipelines, deriving **CalFile– 569** *Secondary Standard stars - external INT preparatory programme* .

The consortium prepares for a **LINUX** parallel cluster for parallel processing, particularly for the image pipeline.

Further, the consortium prepares for advanced object oriented databasing of the source lists that can be extracted from the calibrated images, following the prime objective of the VST/**OmegaCAM**: the finding and identifying of special targets for the VLT. This system should be designed as closely as possible to the DFS pipeline in order to avoid duplication of work.

7.1 Photometric Programme

Request for technical time at the ESO@2.2m telescope

UBVRI STANDARD FIELDS FOR THE PHOTOMETRIC CALIBRATION OF THE OMEGACAM IMAGES

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ABSTRACT
We propose to create a set of 60×60 arcmin^2 equatorial standard star fields, separated by 3 hours in right ascension, plus 6 cluster fields, and one polar field, in order to enable the photometric calibration of the wide field images from the OmegaCam mounted on the VST telescope. We plan to provide UBVRI standard magnitudes with an accuracy of ~ 0.01 magnitudes in the Johnson-Cousins photometric system down to $V \sim 20$, as defined by the set of Landolt (1992) standard stars. These fields will become the basic tools for the photometric calibration of the OmegaCam data and for the routine mapping and daily maintenance of the photometric capabilities of the camera and of the photometric conditions of the sky at Paranal. We plan to use the results of this survey not only for the fundamental definition of the photometric standards, but also for the development of the OmegaCAM procedures.

Night Request:
4 nights in April 2000 (bright time)
4 nights in July 2000 (bright time)
4 nights in October 2000 (bright time)
4 nights in January 2001 (bright time)

Justification
The VLT survey Telescope (VST) is a 2.6m telescope which will be contructed by the Napoli Observatory and managed by ESO on Cerro Paranal. The telescope's main purpose is to carry out long term surveys and to provide the selection of targets for VLT science. The telescope will be equipped with a wide field CCD mosaic camera (OmegaCam), that will be built by a Consortium of Dutch, German, and Italian institutes. According to the present schedule, the camera should be in operation in Spring 2002.

OmegaCam is a CCD mosaic camera with 16384×16384 pixels covering a field of approximately one square degree with very good sampling (0.21 arcsec/pixel). OmegaCam will be the only instrument mounted on VST for many years and it is expected to operate for at least 10 years.

In order to: 1) make good scientific use of the camera, 2) fulfill the various photometric requirements anticipated in the OmegaCam project, and in particular the routine operations and maintenance of the photometric system, and 3) monitor the photometric conditions of the sky at Paranal, it is mandatory to prepare a photometrically internally consistent and homogeneous set of appropriate 60×60 arcmin^2 standard fields, which can garantee a photometric calibration at a level of 0.01 magnitudes throughout the year in the UBVRI Johnson-Cousins system. These bands are the ones which most need a calibration to a standard system, and it is easy to predict that a wide variety of OmegaCam observations will take advantage of the corresponding broad band images.

The most widely used set of primary standard stars for CCD photometry in the Johnson-Cousins system has been provided by Landolt (1992, AJ, 104, 340), who gives magnitudes for 526 stars centered on the equator and located in a set of standard regions which cover an area typically smaller than 30×30 arcmin^2 and a magnitude interval $11.5 < V < 16.0$. Here we propose to extend the set of standards provided by Landolt both in magnitude (most of the Landolt stars have magnitudes too bright to be observed with a 2.5m telescope) and in covered area. The Landolt standards are too bright, and saturate even with very short exposures when observed with a 2.5m telescope. Morover, it is of fundamental importance to set 60×60 arcmin^2 standard fields. This will make straightforward the calibration and the routine performance checking of OmegaCam (and other large field cameras) without multiple pointings.

In particular, we propose to create a set of 60×60 arcmin^2 equatorial field, separated by 3 hours in right ascension, centered on the 8 fields to which Landolt dedicated most of his efforts, i.e., the Selected Areas: 92, 95, 98, 101, 104, 107, 110, 113.

For a better calibration of southern hemisphere observations, we plan to extend the original set of Landolt standard fields to a group of star clusters including some off the equator (Fornax, Carina, NGC 2818, M5, Pal 5, NGC 7006), which we have already linked (on a much smaller region) to the Landolt system. We want to prepare also a polar field, which can be pointed to any time during the year to ensure photometric homogeneity and to help to determine the extinction coefficents at the beginning of each night.

The OmegaCAM consortium believes that the current project is a necessary step to settle and understand the problems related to the use of multi-element wide field CCDs for photometric observations (e.g. the handling of the variations in time of the relative gain of CCD chips with respect to each other is yet unclear). We intend to transport this knowledge to the OmegaCAM project. Indeed, we plan to use the results of this survey not only for the still fundamental definition of the photometric standards, but also for the development of the OmegaCAM procedures. The fact that such procedures have not crystalized yet for the 2.2m and are still subject of intense study, illustrates the need for preparations well in advance of the commissioning of OmegaCAM, after which the instrument is supposed to function on a routine basis for many years.

In view of the known differences between the present filter set and the standard UBVRI bands at the WFI@2.2, *please, note that this project can be carried out only when the new set of* **standard** *UBVRI filters will be available at the WFI@2.2 camera.*

Execution

We want to prepare a set of 60×60 arcmin^2 equatorial standard star fields, separated by 3 hours in right ascension, plus 6 cluster fields, and one polar field, in order to enable the calibration of the wide field images from the OmegaCam. For the moment, we plan to provide UBVRI standard magnitudes in the Johnson-Cousins photometric system down to $V \sim 20$, as defined by the set of Landolt (1992) standard stars. These fields will become the basic tools for the photometric calibration of the OmegaCam data and for the routine mapping and daily maintenance of the photometric capabilities of the camera.

Telescope Justification
We need to cover 60×60 arcmin^2 fields, and the WFI@2.2 camera, with its 30×30 arcmin^2 field, is the only suitable instrument in the southern hemisphere.

Mode Justification
This is a typical project which would mostly benefit from service mode observations, as it can be carried out only during photometric nights. However, at the moment service observing is not available at the 2.2m.

Strategy
We intend to issue a contract for one year to a person who will be fully dedicated to the reduction and analysis of the data on a dedicated workstation. We will mainly use the software specifically written for the treatment of photometric standards by one of us (PBS). This software has been widely used and tested while performing the photometric calibration of images collected in more than 200 nights in more than 60 distinct runs. We plan to measure the magnitudes of all the stars in the covered field, and calibrate them to the Landolt system. The data will also be used to verify prototypes of the OmegaCam pipeline and this will also allow the cross-calibration of the data reduction code.

BackUp Programme
We need photometric nights. In case of not photometric weather we will perform an observing program of ours for the WFI@2.2 camera, compatible with the moon illumination.

Lunar Phase
As we need to measure bright stars we have no specific requirement on the moon phase, though, if gray time is available, the accuracy of the photometry would be improved.

Why Nights
We propose to observe 15 60×60 arcmin^2 fields equally spaced in right ascension, using 5 different filters (UBVRI). In each band, we propose the following exposure sequence for an extension of the Landolt standards from $V \sim 12$ to $V \sim 20$: 10s and 2×300s, in order to properly measure the magnitudes with the proposed accuracy of all the stars down to V=20. (Possible shutter effects will be mapped during the day with the dome flat fields.) Each sequence must be repeated 4 times to cover a 60×60 arcmin^2 field with the 30×30 arcmin^2 WFI@2.2 camera, for 5 filters. Presently, the overhead for each single exposure at the WFI@2.2 is 2.5 minutes. We need to repeat each short exposure twice during the night for an accurate estimate of the extinction coefficents. The double long exposure and the short exposure repeat will allow dithering, thus improving the photometric accuracy. And we need to repeat the short exposure observations on each field for three nights, for a better mapping of the extinction and to reach the proposed accuracy. This means a total of $2.5 \times 4 \times 5 \times 2 \times 3 = 300$ minutes/per field for the short exposures plus $(5 + 5 + 2.5 + 2.5) \times 4 \times 5 = 300$ minutes/field for the long exposures. This sums up to 10 hours of exposures per field. We propose to observe 4 fields per run, for a total of 40 hours.

We therefore request 4 runs, 4 nights each, spread over a period of 1 year.

It must be clearly stated that only with 4 night runs the project can be properly carried out.

Targets

```
Object & Right Ascension & Declination & Equinox

SA 104      12 41 04    -00 37 11    J2000
NGC 5904    15 16 02    +02 15 51    J2000
SA 107      15 37 25    +00 18 34    J2000
Polar       00 00 00    -90 00 00    J2000
NGC 6656    18 33 21    -23 56 44    J2000
SA 110      18 40 45    +00 01 51    J2000
NGC 7099    21 37 32    -23 24 23    J2000
SA 92       00 53 14    +00 46 02    J2000
Fornax      02 39 53    -34 30 16    J2000
SA 95       03 52 40    -00 05 22    J2000
Carina      06 41 36    -50 57 58    J2000
SA 98       06 51 27    -00 15 37    J2000
NGC 2818    09 16 01    -36 37 36    J2000
SA 101      09 54 51    -00 27 28    J2000
SA 113      21 40 35    +00 41 45    J2000
```

7.2 Planning Photometric programmes

B,V,R,i – Status of the preparatory program at the ESO2.2+WFI as of FDR date

The preparatory program at the ESO2.2+WFI was intended to provide suitable data for testing the photometric calibration procedures of **OmegaCAM**. This programme is handled by the Padua group of the consortium. Observing time was allocated in three separate runs, for a total of 12 nights (Apr 20-26,2000; July 9-13, 2000; Feb. 3-7 2001). Of these, 6 were photometric.

The original program was intended to cover 8 60×60 arcmins^2 standard fields in the B,V,R,i bands. Given the field size of the WFI, this requires four pointings per field. For each pointing our aim was to obtain long and short exposures, to assure the coverage with adequate S/N of a wide magnitude range.

The calibration was derived by observation of Landolt's standard fields. Because of the small sky area covered by typical Landolt fields, a determination of the chip to chip zero point and calibration coefficent dependence required 8 separate pointings.

Because the actual observing time was $\sim 50\%$ of the allocated one, and about 40% of the allocated time was not in photometric conditions, the program was only partly completed. We got complete observations for three fields, and partial coverage for 4 fields.

STD FIELD	RA	DEC	completion
SA 101	09 55 57	-00 23 14	50%
SA 104	12 42 31	-00 38 36	75%
SA 107	15 39 36	-00 12 36	25%
SA 110	18 42 21	+00 14 52	100%
NGC 5904	15 18 33	+02 04 58	100%
SA113	21 40 35	00 41 45	50%
SA98	06 51 52	-00 19 54	100%

The first step of analysis of the data has been the computation of the individual CCD photometric constant and color term. It turns out that the main limitation to the photometric accuracy is the inhomogeneity across the mosaic area (Δmag> 0.1) which may be attributed by additional-light pattern cause by internal reflections off the telescope corrector (cf. Capaccioli et al. The Capodimonte Deep Field: data reduction and characterisation of the ESO wide field imager). Work is in progress to determine the best strategy to deal with this problem.

Meanwhile we are committed to complete the analysis of the available data, to highlight the problems which may be encountered in the different steps of the calibration process. For the three fields for which we could obtain complete data we will produce table of B,V,R,i magnitudes for stars in a wide range of magnitudes which can be used to monitor WFI performances and in the preliminary operation with **OmegaCAM**.

The programme is expected to produce tables with magnitudes and positions for the stars in the observed fields.

Sloan bands- u', g', r',i'

OmegaCAM will employ the standard set of Sloan bands and secondary standards in the Sloan band, covering a 1 square degree fov, are highly wanted. The WFI@2.2m does not have these filters and the preperatory programme can not provide this. In an attempt to solve this problem, the consortium, together with VISTA, has initiated another campaign at the INT wide field imager, La Palma (for the fields SA 104, SA 107, SA 110, SA 112 and SA 92).

Calibration of standard fields with OmegaCAM

As the **OmegaCAM** filters will be different from those available at the ESO2.2+WFI, it was agreed that the actual calibration of the 1 square degree standard field will have to be done with OmegaCAM itself (**req.**569).

In the User requirements and the Calibration plan we have specified such an activity **req. 569** *secondary standards*. Details can be found there. The programme will last at least for a year and will require a substantial amount of observing time.

Because this activity is going to extend well after the installation and commissioning phase of **OmegaCAM**, it is outside the original scope of the financing obtained by **OmegaCAM**. Therefore a special application will need to be presented and ESOs help might be needed.

A1 LIST of CALIBRATION REQUIREMENTS

A2 LIST of RAW CALIBRATION DATA

	volume per **req.**run and per year
RawData– 523 *CCD gain*	10Gb 0.52Tb
RawData– 531 *Dark current*	0.75Gb 40Gb
RawData– 541 *Raw Bias frame*	5Gb 0.51Tb
RawData– 542 *Dome flat frame*	2Gb 0.66Tb
RawData– 543 *Twilightflat frame*	10Gb 3.3Tb
RawData– 547 *Quick check*	0.5Gb 115Gb
RawData– 562 *Monitor*	0.5Gb 0.5Tb
RawData– 563 *Zeropoint- Key*	2.5Gb 0.8Tb
RawData– 564 *Zeropoint - User*	2.5Gb 0.8Tb
RawData– 565 *User -> key*	25Gb 25Gb
RawData– 569 *Secondary Standards*	64 Gb 1.5Tb

A3 LIST of DFS I/O CALIBRATION FILES

volume per file and per year

CalFile– 521 *QC-parameter read_noise*	2 kb, 1 Mb
CalFile– 522 *bad/hot pixel map*	0.25Gb 25Gb
CalFile– 523 *QC parameter gain e^-/ADU*	2kb .1Mb
CalFile– 531 *dark count rate for each CCD*	2kb .1Mb
CalFile– 532 *Particle event rate*	2kb .1Mb
CalFile– 533P *CCD Linearity Plot*	2kb .1Mb
CalFile– 533M *CCD Linearity Map*	0.25Gb 0.3Tb
CalFile– 534 *charge transfer efficiency factors*	.2Mb .4Mb
CalFile– 535 *Cold pixel map*	.25Gb 1Gb
CalFile– 536 *CCD Hysteresis*	2kb 2kb
CalFile– 541 *Master Bias frame*	1Gb 104Gb
CalFile– 542 *Master Domeflat frame*	1Gb 0.330Tb
CalFile– 542L *Dome Lamp*	2kb 1Mb
CalFile– 543 *Master Twilightflat frame*	4Gb 1.3Tb
CalFile– 544 *Nightsky flat frame*	1Gb 1Tb
CalFile– 545 *ff-fringe*	1Gb 0.3Tb
CalFile– 546 *Master flatfield*	1Gb 0.3Tb
CalFile– 547 *Quick check*	1Gb 0.33Tb
CalFile– 547r *Quick check - day report*	3kb 1Mb
CalFile– 548F *Illumination correction fit coefficients*	15kb 180kb
CalFile– 548 *Illumination correction*	1Gb 10Gb
CalFile– 554 *PSF anisotropy*	.1Mb 1 Mb
CalFile– 556 *Astrometric solution - Guide CCD*	2 kb 1 Mb
CalFile– 562Su *Sky brightness-u'*	1 kb 1 kb
CalFile– 562Sg *Sky brightness-g'*	1 kb 1 kb
CalFile– 562Sr *Sky brightness-r'*	1 kb 1 kb
CalFile– 562Si *Sky brightness-i'*	1 kb 1 kb
CalFile– 562 *Extinction-night report*	2 kb 1 Mb
CalFile– 562T *Photom + Sky*	5Mb 2Gb
CalFile– 563 *Zeropoint - key bands*	4kb 1.2Mb
CalFile– 564 *zeropoint - User bands*	4kb 1.2Mb
CalFile– 565 *User -> key*	4kb 1Mb
CalFile– 565C *composite -> monolithic*	4kb 1Mb
CalFile– 569 *Secondary Standard Catalog*	1 Mb 1 Gb

A4 LIST of DFS INPUT REFERENCE CATALOGUES

CalFile– in1 *US-NAVAL Observatory A2.0* 6 Gbyte
CalFile– 569E *Primary Standard stars - external Landolt fields* 100 Mb
CalFile– 564E *Standard extinction curve* 0.1Mb

NOTE:

Both the preparatory programme and **req.**569 will produce **CalFile– 569** *Secondary standards*.
CalFile– 569 *Secondary Standard stars - preparatory programme* 100 Mb

A5 CALIBRATION TIME TABLES

Calibration Time Table for Commissioning Phase

Req.	Description	Frequency	DayTime	NightTime
	DAILY HEALTH CHECKS: each day of CP		TIME NEEDED/DAY	
5.2.1	CCD read noise - doit	1/day	5 m	0
5.4.1	Bias - doit	1/day,(1)	15 m	0
5.4.2	FF - dome key bands + user bands - doit	1/day	10 m	0
5.4.3	FF - twilight	2/day	25 m	0
5.4.4	FF - night sky	1/day	0	0
5.4.7	Quick check - doit	1/day	3 m	0
5.6.2	Photometry - monitoring	3/night	0	12 m
5.6.3	Photometry - zeropoint key bands - doit	1/night	0	12 m
	Total DAILY		58 m	24 m
	WEEKLY CHECKS during CP		TIME NEEDED/WEEK	
5.2.2	Hot pixels	2/week	0	0
5.2.3	CCD gain	1/week	1 h	0
5.3.1	CCD Dark Current - doit	1/week	3 h	0
5.3.2	CCD Particle Event Rate	1/week	0	0
	Total WEEKLY		4 h	0 h
	SPECIAL CHECKS DONE ONLY ONCE DURING CP		TIME NEEDED/OPERATION	
5.2.4	Electromagnetic Compatibility	1/CP	4 h	0
5.2.5	Electrical cross talk	1/CP	0	4 h
5.3.3	CCD Linearity	1/CP	0	0
5.3.4	CCD Charge Transfer Efficiency	1/CP	30 m	0
5.3.5	CCD Cold pixels	1/CP	0	0
5.3.6	CCD hysteresis, strong signal	1/CP	0	30 m
5.4.5	FF - Fringing	1/CP,1/lngwvscience	0	0
5.4.6	FF - master flat and weight map	1/new_ff	0	0
5.4.8	Illumination correction	1/CP	0	2 nights
5.5.1	Position of Camera in focal plane	1/fltrchng,1/CP	0	2 h
5.5.2	Telescope Pointing	1/CP,1/pntngchng,(1)	0	10 m
5.5.3	Telescope and Field Rotator tracking	2/pntngchng	0	2 m
5.5.4	PSF Anisotropy	1/CP,1/optclchng	0	2 m/pntng
5.5.6	The astrometric solution for Guide CCD's	1/CP	0	0
5.6.1	Shutter Timing	1/CP	1 h	0
5.6.5	Filter band passes - user bands vs key bands	1/CP	0	5 m/fltr
5.6.6	Dependency on rotator angle	1/CP	1 day	2 h
5.6.7	Linearity (as a function of flux)	1/CP	0	6 h
5.6.8	Detection limit and ETC calibrations	1/CP	0	0
5.6.9	Secondary Standards	2/CP,(2)	0	2 h
5.7.1	Camera focus - doit (filter thickness)	1/CP	0	4 h
5.7.2	Ghosts - ADC	1/CP	0	1 h/fltr
	ROUTINE TASKS, also done in CP			
5.6.4	Photometry - zeropoint user bands	1/night when used	0	5 m/fltr
5.5.5	The astrometric solution for templates - doit	-	0	0

(1) To Be Determined by Experience
(2) Started in CP, continuing through first year of RP

```
{\begin{verbatim}
---------------------------------------------------------------------------------------------------------------
                   Calibration Time Table for Routine PHASE  for OPERATIONS AND MAINTENANCE
---------------------------------------------------------------------------------------------------------------
Req.   Description                                    Frequency              DayTime          NightTime
---------------------------------------------------------------------------------------------------------------
       DAILY CHECKS / also after each maintenance activity                       TIME NEEDED/DAY
5.2.1  CCD read noise - doit                          1/day                        5 m               0
5.4.1  Bias - doit                                    1/day,(1)                   15 m               0
5.4.2  FF - dome key bands + user bands - doit        1/day                       10 m               0
5.4.3  FF - twilight                                  1/day                       25 m               0
5.4.4  FF - night sky                                 1/day                        0                 0
5.4.5  FF - Fringing                                  use fringed science data     0                 0
5.4.6  FF - master flat and weight map                use data for 5.4.2 and 5.4.3 0                 0
5.4.7  Quick check - doit                             1/day                        3 m               0
5.6.2  Photometry - monitoring                        3/night                      0                12 min
5.6.3  Photometry - zeropoint key bands - doit        1/night                      0                12 min
5.6.4  Photometry - zeropoint user bands              1/night                      0                 5 m/fltr
---------------------------------------------------------------------------------------------------------------
       Total daily                                                                58 m              24 min
---------------------------------------------------------------------------------------------------------------
       WEEKLY CHECKS                                                             TIME NEEDED/WEEK
5.2.2  Hot pixels                                     2/week                       0                 0
5.2.3  CCD gain                                       1/week                       1 h               0
5.3.1  CCD Dark Current - doit                        1/week                       3 h               0
5.3.2  CCD Particle Event Rate                        1/week                       0                 0
5.3.3  CCD Linearity                                  1/month                      0                 0
---------------------------------------------------------------------------------------------------------------
       Total weekly                                                                4 h               0 h
---------------------------------------------------------------------------------------------------------------
       QUARTERLY - YEARLY CHECKS                                                 TIME NEEDED/OPERATION
5.3.4  CCD Charge Transfer Efficiency                 2/year                      30 m               0
5.3.5  CCD Cold pixels                                4/year                       0                 0
5.3.6  CCD hysteresis, strong signal                  -                            0                 0
5.4.8  Illumination correction- quick verification    1/month                       0               30 m
5.5.1  Position of Camera in focal plane              1/year,user supplied filter  0                 2 h
5.5.2  Telescope Pointing                             1/year,1/pntngchng,(1)       0                10 m
5.5.3  Telescope and Field Rotator tracking           (1)                          0                 2 m
5.5.4  PSF Anisotropy                                 4/year,1/optclchng           0                10 m
5.2.4  Electromagnetic Compatibility                  1/year,1/syschng,(1)         4 h               0
5.6.1  Shutter Timing                                 4/year,(1)                   1 h               0
5.5.5  The astrometric solution for templates - doit  -                            0                 0
5.5.6  The astrometric solution for Guide CCD's       -                            0                 0
5.6.5  Filter band passes - user bands vs key bands   -                            0                 0
5.6.6  Dependency on angle ADC, rotator               -                            0                 0
5.6.7  Linearity (as a function of flux)              -                            0                 0
5.6.8  Detection limit and ETC calibrations           -                            0                 0
5.6.9  secondary standards                            first year of operations     0       2 bright nights/month
---------------------------------------------------------------------------------------------------------------
(1) To Be Determined by Experience
\end{verbatim}}
```

A6 SKYGRID of PROJECTION CENTRES

The following table describes a grid on the sky for projection and co-addition purposes in a condensed format. It contains 94 strips as function of decreasing declination ($0° \geq \delta \geq -90°$). For each strip the size in degrees and the number of $1° \times 1°$ fields per strip is given. The last column contains the overlap between fields in %. By mirroring the grid along the equator one obtains a grid for the northern hemisphere. The combination of the grids for both hemispheres is a grid for the entire sky.

	$-\delta$	size				$-\delta$	size				$-\delta$	size		
	°	°	#	%		°	°	#	%		°	°	#	%
1	0.00	360.00	378	5.0	33	30.64	309.74	323	4.3	65	61.28	173.01	182	5.2
2	0.96	359.95	378	5.0	34	31.60	306.64	320	4.4	66	62.23	167.71	176	4.9
3	1.91	359.80	378	5.1	35	32.55	303.44	317	4.5	67	63.19	162.36	170	4.7
4	2.87	359.55	378	5.1	36	33.51	300.16	314	4.6	68	64.15	156.97	164	4.5
5	3.83	359.20	377	5.0	37	34.47	296.80	311	4.8	69	65.11	151.54	158	4.3
6	4.79	358.74	376	4.8	38	35.43	293.35	308	5.0	70	66.06	146.06	152	4.1
7	5.74	358.19	375	4.7	39	36.38	289.83	304	4.9	71	67.02	140.54	146	3.9
8	6.70	357.54	374	4.6	40	37.34	286.22	300	4.8	72	67.98	134.98	140	3.7
9	7.66	356.79	373	4.5	41	38.30	282.53	296	4.8	73	68.94	129.39	134	3.6
10	8.62	355.94	372	4.5	42	39.26	278.76	292	4.7	74	69.89	123.76	128	3.4
11	9.57	354.99	371	4.5	43	40.21	274.91	288	4.8	75	70.85	118.09	122	3.3
12	10.53	353.94	370	4.5	44	41.17	270.99	284	4.8	76	71.81	112.39	116	3.2
13	11.49	352.79	369	4.6	45	42.13	266.99	280	4.9	77	72.77	106.66	110	3.1
14	12.45	351.54	368	4.7	46	43.09	262.92	276	5.0	78	73.72	100.90	104	3.1
15	13.40	350.19	367	4.8	47	44.04	258.78	272	5.1	79	74.68	95.11	98	3.0
16	14.36	348.75	366	4.9	48	45.00	254.56	267	4.9	80	75.64	89.30	92	3.0
17	15.32	347.21	365	5.1	49	45.96	250.27	262	4.7	81	76.60	83.46	86	3.0
18	16.28	345.57	363	5.0	50	46.91	245.91	257	4.5	82	77.55	77.59	80	3.1
19	17.23	343.84	361	5.0	51	47.87	241.48	252	4.4	83	78.51	71.71	74	3.2
20	18.19	342.01	359	5.0	52	48.83	236.99	247	4.2	84	79.47	65.80	68	3.3
21	19.15	340.08	357	5.0	53	49.79	232.43	242	4.1	85	80.43	59.88	62	3.5
22	20.11	338.06	355	5.0	54	50.74	227.80	237	4.0	86	81.38	53.94	56	3.8
23	21.06	335.95	353	5.1	55	51.70	223.11	232	4.0	87	82.34	47.98	50	4.2
24	22.02	333.74	350	4.9	56	52.66	218.36	227	4.0	88	83.30	42.01	44	4.7
25	22.98	331.43	347	4.7	57	53.62	213.54	222	4.0	89	84.26	36.03	38	5.5
26	23.94	329.04	344	4.5	58	54.57	208.67	217	4.0	90	85.21	30.04	32	6.5
27	24.89	326.55	341	4.4	59	55.53	203.74	212	4.1	91	86.17	24.05	26	8.1
28	25.85	323.97	338	4.3	60	56.49	198.75	207	4.1	92	87.13	18.04	19	5.3
29	26.81	321.31	335	4.3	61	57.45	193.71	202	4.3	93	88.09	12.03	13	8.1
30	27.77	318.55	332	4.2	62	58.40	188.61	197	4.4	94	89.04	6.02	7	16.4
31	28.72	315.70	329	4.2	63	59.36	183.46	192	4.7	95	89.90	0.63	1	-
32	29.68	312.77	326	4.2	64	60.32	178.26	187	4.9					

A7 CALIBRATION VERIFICATION MATRIX

5.2.1 Req.– *Cat I: CCD read noise - doit* . . . . ⊔

Required accuracy, constraints:

Readout noise less than 5e$^-$.
Variation in readout noise w.r.t. reference value less than 0.5e$^-$.

5.2.2 Req.– *Cat I: Hot pixels* . . . . ⊔

Required accuracy, constraints:

Number of hot pixels to be determined by experience/lab values.
The total number of bad pixels (hot pixels + cold pixels) is less than 80000 (checked in **req. 535** *Cold pixels*
Difference in number of hot pixels w.r.t. reference value, less than 100.

5.2.3 Req.– *Cat I: CCD gain* . . . . ⊔

Required accuracy, constraints:

Accuracy: In units of e$^-$/ADU, from lab values or found empirically. Variation in time less than 1%.

5.2.4 Req.– *Cat III: Electromagnetic Compatibility* . . . . ⊔

Required accuracy, constraints:

Difference between read noise under operational conditions and the standard read noise measurement should be smaller than 20% for external and 10% for internal causes of interference.

5.2.5 Req.– *Cat III: Electrical cross talk* . . . . ⊔

Required accuracy, constraints:

10^{-5}

5.3.1 Req.– *Cat I: CCD Dark Current - doit* . . . . ⊔

Required accuracy, constraints:

Dark count rate should be less than the equivalent of 3 e$^-$/pixel/hour in ADUs excluding bad pixels.
Accuracy of determining particle event rate 1 ADU/cm^2/hour.
Particle event rates should be identical for each chip.

5.3.2 Req.– *Cat I: CCD Particle Event Rate* . . . . ⊔

Required accuracy, constraints:

better than 1 ADU/cm^2/hour

5.3.3 Req.– *Cat I: CCD Linearity* . . . . ⊔

Required accuracy, constraints:

better than 1% on the photometric scale

5.3.4 Req.– *Cat III: CCD Charge Transfer Efficiency* . . . . ⊔

Required accuracy, constraints:

CTE $>$ 0.999995 per parallel or serial shift.

5.3.5 Req.– *Cat I: CCD Cold Pixels* . . . . ⊔

Required accuracy, constraints:

Quality Check: Number of hot pixels to be determined by experience/lab values. The total number of bad pixels (hot pixels + cold pixels) is less than 80000. Difference in number of cold pixels w.r.t. reference version less than 100.

5.3.6 Req.– *Cat III: CCD Hysteresis, strong signal* . . . . ⊔

5.4.1 Req.– *Cat I: Bias - doit* . . . . ⊔

Required accuracy, constraints:

The required accuracy per pixel in the master bias frame is "nominal read-outnoise/$\sqrt{10}$".

For the quality check: Since an overscan correction is performed, the deviation of the mean level of master bias (bias level) from zero, should be less than TBD.

5.4.2 Req.– *Cat I: Flat-field - dome key bands + user bands - doit* . . . . ⊔

Required accuracy, constraints:

Accurately measuring pixel-to-pixel gain variations as small as 1%. Re-insertion of the filter shall not alter the flat field stucture by more than 0.3% (rms, measured over the full detector area).

5.4.3 Req.– *Cat I: Flat-field - twilight* . . . . ⊔

Required accuracy, constraints:

Mean levels should be approximately 20000 ADU.

5.4.4 Req.– *Cat I: Flat-field - night sky* . . . . ⊔

Required accuracy, constraints:

This procedure would benefit from a prior detection and masking of bright objects. If no masks of bright objects are available, then a minimum of 15 frames should be included.

5.4.5 Req.– *Cat I: Flat-field - fringing* . . . . ⊔

5.4.6 Req.– *Cat I: Flat-field - master flat* . . . . ⊔

5.4.7 Req.– *Cat I: Quick detector responsivity check-doit* . . . . ⊔

Required accuracy, constraints:

1%

5.4.8 Req.– *Cat II: Illumination correction* . . . . ⊔

Required accuracy, constraints:

better than 1% for the amplitude over a single CCD.

5.5.1 Req.– *Cat III: Position of Camera in focal plane* . . . . ⊔

Required accuracy, constraints:

Internal precision: 0.3 pixel. External precision limited by reference catalog

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5.5.2 Req.– *Cat III: Telescope Pointing and offsetting* . . . . ⊔

Required accuracy, constraints:

1 arc second

5.5.3 Req.– *Cat III: Telescope and Field Rotator tracking* . . . . ⊔

Required accuracy, constraints:

VST requirements:
free tracking better than 0.2 arcsec r.m.s.
autoguiding tracking better 0.05 arcsec

5.5.4 Req.– *Cat III: PSF Anisotropy* . . . . ⊔

Required accuracy, constraints:

better than 1%

5.5.5 Req.– *Cat I: The astrometric solution for templates - doit -see 6.3.4* . . . . . . ⌴

5.5.6 Req.– *Cat III: The astrometric solution for Guide CCD's* . . . . ⌴

Required accuracy, constraints:

1 arcsec rms for the accuracy with respect to the external standard;

External precision is driven by the position reference catalog. This is in the case of the USNO-A2 catalog of the order 0.3" with possible systematic excursions to 1".

5.6.1 Req.– *Cat III: Shutter Timing* . . . . ⌴

Required accuracy, constraints:

Timing error less than 0.2%.

5.6.2 Req.– *Cat I: Photometric Calibration - monitoring* . . . . ⌴

Required accuracy, constraints:

all photometry better than 1-2% on the photometric scale.

5.6.3 Req.– *Cat I: Photometric Calibration - zeropoint keybands - doit* . . . . ⌴

Required accuracy, constraints:

1% on the photometric scale

5.6.4 Req.– *Cat I: Photometric Calibration - zeropoint user bands* . . . . ⌴

Required accuracy, constraints:

2% on the photometric scale for broad bands and 5% for narrow band filters.

5.6.5 Req.– *Cat I: Filter band passes - user bands vs key bands* . . . . ⌴

Required accuracy, constraints:

10% on the photometric scale (formal spec) and 2% (goal) for broad band filters
1% for composite -> key

5.6.6 Req.– *Cat III: Dependency on angle - ADC, rotator/reproducibility* . . . . ⌴

Required accuracy, constraints:

1% on the photometric scale

5.6.7 Req.– *Cat III: Linearity (as a function of flux)* . . . . ⌴

Required accuracy, constraints:

Better than 1% on the photometric scale

5.6.8 Req.– *Cat III: Detection limit and ETC calibrations* . . . . ⊔

Required accuracy, constraints:

10 % in detection limit

5.6.9 Req.– *Cat I: Secondary Standards* . . . . ⊔

Required accuracy, constraints:

0.02 mag in individual secondary standards stars. The sources in **CalFile– 569** *s*hould cover a FoV of approximately 1.2 square degree.

5.7.1 Req.– *Cat III: Camera focus/tilt* . . . . ⊔

5.7.2 Req.– *Cat III: Ghosts - ADC* . . . . ⊔