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La Silla SciOps

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The Wide-field Imager Handbook

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1.0	23/02/04	All	creation
1.1	23/02/04	All	WFI manual archived as a module
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2.0	3/05/05	All	Alognment of document version with module version

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Important Notice

Some of the information in this document might be outdated. Please go to the La Silla SciOps web pages at

http://www.ls.eso.org/lasilla/sciops

to get the latest information.

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Chapter 1

Introduction

1.1 Purpose

The present document describes the Wide Field Imager camera, henceforth WFI, of the MPG/ESO 2.2-m telescope at La Silla and its operation. It is intended as an aid for users preparing proposals and/or observations with WFI. The information here supersedes that given in the previous WFI Manual [4]. This document also supersedes and replaces other two documents: the *WFI Templates Reference Manual* [18], and the *WFI Calibration Plan* [1].

The intended audience are the astronomers that have been awarded observing time with WFI, the SciOps support astronomers, and TIOs.

1.2 Scope

This handbook is intended to assist the user throughout the life cycle of an observing programme with the WFI:

Preparation of proposals: Chapter 2 (description of the instrument and its capabilities) and Chapter 5 (for the decision between visitor or service mode) are intended to be used during Phase I preparations.

Preparation of observations: Chapters 3 and 4 (for the preparation of the exposures to be made either in imaging or spectroscopic mode) and 5 (for details about the practical execution of the observations) are intended to be used during Phase II preparations. The service mode user should study carefully Sec. 5.7, which discusses how to set the observing constraints.

Data reduction and calibration: Chapter 7 shows how to reduce and calibrate WFI data using an ECLIPSE based set of special purpose routines. This chapter is very schematic, and is intended to give prospective users a general idea of what is needed to reduced WFI data, and thus it might be useful during Phase II.

Calibration plan: Chapter 6 describes the WFI calibration plan, and should be read during Phase II, so that the users can determine whether they will have special calibration requirements.

1.3 Applicable documents

The latest version of the WFI handbook is always accessible through the ESO - La Silla home page on the World Wide Web (URL: http://www.ls.eso.org). Any recent changes in the areas covered by this document are also highlighted there. We keep one source and output from it a PDF and an html version. If all else fails, a printed copy can be requested from the Visiting Astronomers Section at ESO Headquarters in Garching (Internet: visas@eso.org). However, please note that new printed versions of the WFI handbook are prepared only after major revisions of the document.

1.4 Reference documents

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1.5 User feedback and inquiries

ESO values and strongly encourages feedback from its users on the suitability of its equipment for their research. The WWW pages referred to above also describe (and include) means to contact relevant support staff. Electronic mail can also be sent directly to ls-imaging@eso.org.

A printed copy of this handbook will always be available in the control room of the 2.2-m telescope. Any observations about this document can be written into that copy which, therefore, should not be removed.

1.6 Abbreviations and acronyms

ADU	Analog Digital Unit
ASCII	American Standard Code for Information Interchange
A/D	Analog-to-Digital
ADC	Atmospheric Dispersion Corrector
BOB	Broker of Observation Blocks
CCD	Charge Coupled Device

DCS	Detector Control System
DAT	Digital Audio Tape
DLT	Digital Linear Tape
ESO	European Southern Observatory
eu	M2 encoder unit (1.25 μm)
FIERA	Fast Imager Electronic Readout Assembly
FWHM	Full Width at Half Maximum
FF	Flat Field
FOV	Field Of View
ftp	file transfer protocol
GUI	Graphical User Interface
ICS	Instrument Control System
IDL	Interactive Data Language
IRAF	Image Reduction and Analysis Facility
LAN	Local Area Network
MIDAS	Munich Image Data Analysis System
MPG	Max-Planck-Gesellschaft
M1, M2	primary and secondary, respectively, mirror of the telescope
NS	Night Sky
NTT	New Technology Telescope
OB	Observation Block
OS	Observing software
PRNU	Pixel Response Non-Uniformity
PSF	Point Spread Function
QE	Quantum Efficiency
rms	root mean square
RAID	Redundant Array of Inexpensive/Independent Disks
RAM	Random Access Memory
RTD	Real Time Display
TBC	To Be Completed, To Be Confirmed
TBD	To Be Decided, To Be Done
TCS	Telescope Control System
URL	Uniform Resource Locator (a WWW address)
VLT	Very Large Telescope
WFI	Wide Field Imager at the 2.2-m telescope
WWW	World Wide Web

1.7 Glossary

Note that the operations scheme for the WFI emulates the VLT operations model. Therefore, this document partly uses VLT-like jargon. However, in many instances this similarity exists only at the conceptual level whereas the actual implementation may be quite different.

Autoguider: An imaging device which permits the relative position of the image of an isolated star to be monitored at a frequency of some Hertz. Any deviations from the nominal position are fed back to the TCS in order to be compensated for by corresponding telescope offsets (Sect. 2.1.2.2). The corrections are relative to the tracking of the telescope.

FIERA: The electronics system that prepares the CCD for an exposure, starts and supervises the exposure, reads the data, writes them to the memory of the Real Time Display and sends them to the instrument work station where the files are written to disk in FITS format (Sect. 2.2.1).

FITS: A standard for the format of image files and their associated ancillary parameters (Sects. 2.2.5).

Observation Block: The smallest unit of action that BOB can execute (Chapter 5). It consists of one or several Observing Template signature files.

Observing Template: The 'subatomic' units that constitute an Observation Block. Often they imply only a single exposure, though some also support more complex coordinated operations of both WFI and the telescope (Chapter 5).

Real Time Display: An image display where the images are displayed as they are read out of the detector (Sect. 2.2.1).

Observing Template Signature File: An ASCII file that contains the parameters with which the associated Observing Template shall be executed.

Seeing Monitor: A small telescope which on the basis of differential image motions measures the seeing (Sect. **??**). (URL: http://epu.ls.eso.org/lasilla/dimm/meteo/).

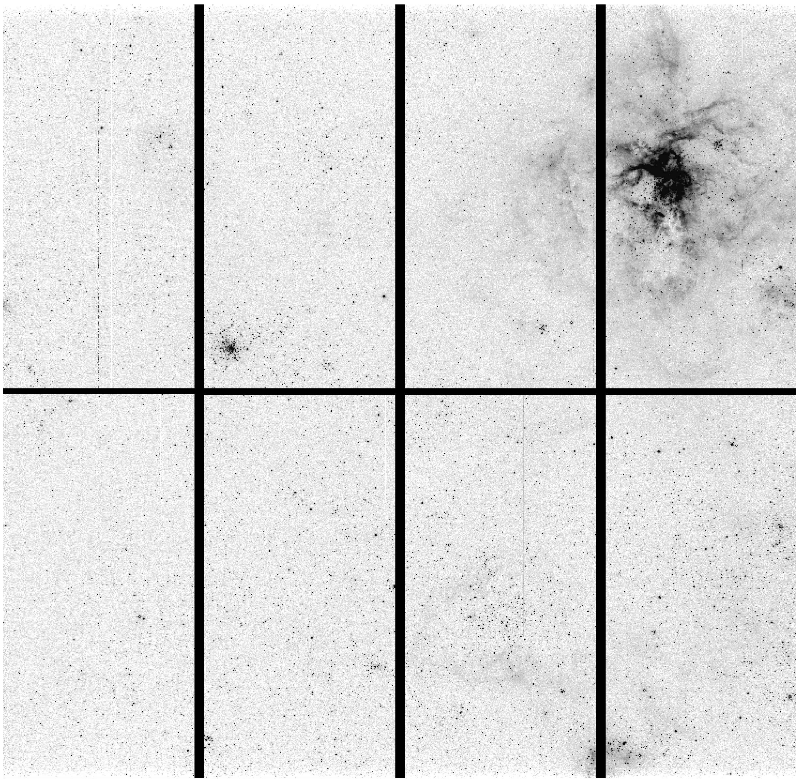
Service Observing: The successful applicants supply the Observatory with Observation Blocks which are executed by ESO staff without presence of the applicants.

TCS: The software system used to control the telescope. For autoguiding, it uses the separate tracker of the WFI and together with the DCS shares the controller over the single instrument shutter.

Visitor Mode: In this alternative mode to service observing, the applicants themselves carry out their observing program.

Chapter 2

Instrument and telescope overview



The Wide Field Imager, WFI, is ESO's current wide-angle camera, mounted on the MPG/ESO 2.2-m telescope at La Silla. With a field-of-view, FOV, of approximately 34'$\times$33', and an image scale of 0.238$''$ per pixel, it samples the Point Spread Function, PSF, at the Nyquist frequency for all but the best seeing conditions. WFI uses one of ESO's FIERA controller to read in under 30 seconds a mosaic of 8 2k$\times$4k, 15 μm pixels, thinned, anti-reflection coated EEV CCDs. Other novel features of the instrument are a large shutter consisting of a rotating roughly semi-circular disk which can be used to obtain exposures as short as 0.2s, and a filter magazine with 46 filters available at all times (it has 50 positions but some are used for calibrations such as beta-lights, pin-holes, and a opaque screen). The detector sits behind a f/5.90 focal reducer camera consisting of two triplet which change the the intrinsic telescope scale of 0.0351$''$ per 15 μm pixel to 0.238$''$/pix. Although the scale is constant to better than 0.08% over the field of view, the double-triplet system introduces sky concentration effects which affect the photometry at the 10% level.

2.1 The MPG/ESO 2.2-m telescope

The MPG/ESO 2.2-m telescope in a nutshell

Longitude:	**70:44:04.54 W**
Latitude:	**-29:15:15.43 S**
Altitude:	**2335 m**
Manufacturer:	**Carl Zeiss**
Operating since:	**Early 1984**
Optical design:	**Ritchey-Chretien**
Free aperture:	**2200 mm**
Focal ratio:	**f/8.0**
Scale:	**11.7″/mm without corrector**
Field of view:	**33 arcmin free from vignetting**
Optical quality:	**d 80% encircled energy = 0.3″**
Focus position:	**Cassegrain**
Moount:	**Equatorial-Fork**
M1 diameter:	**2300 mm**
M1 focal ratio:	**f/3**
M1 shape:	**Hyperbolic**
M1 material:	**Zerodur**
M2 diameter:	**844 mm**
M2 shape:	**Hyperbolic**
M2 material:	**Zerodur**
M2 central obstruction:	**40%**
M2 focussing encoder unit (eu)	**1.25 μm**

The optical system of the 2.2-m telescope is a strict Ritchey-Chretien. This means that the mirror surfaces have been figured to give an aplanatic system, i.e. free from spherical aberration and coma. The two-mirror system gives in the Cassegrain focus a real inverted image on a spherical surface concave towards the incident light beam. The f-ratio of this uncorrected system is f/8.005, giving an image scale of 11.″7/mm. WFI uses a double triplet system to flatten and reduce the focal scale (see below). Figure 2.1 shows an image of the telescope, while the geometry of the 2.2-m telescope optical system is given in Figure 2.2.

The tube of the 2.2-m is an open truss construction, which, to incorporate the possible use of a Coudé focus, necessitated a *modified* Serrurier[1] principle. For focusing, the secondary mirror can be moved within a range of 30 mm along the tube axis, at a speed of 12.5 μm/sec. The focusing of the telescope does not induce detectable image motion at a level of a fraction of an arcsec. Temperature variations induce focus changes at a rate of 66 eu/°C, which are accounted for by the observing software. There is a position dependent focus variation of the order of 120μm from zenith distance of 70°to the zenith. This focus change with telescope position, which is not only on zenith distance, is not corrected for in software, necessitating a manual refocus of the telescope when going to different positions during the night.

[1] After Mark Serrurier, the Caltech graduate that designed the structural parts of the 200-inch Hale telescope at Palomar. He realized that such a large tube could not be made stiff enough, but he could design the tube such that the M1 and M2 deflections were the same in any position, thus maintaining collimation (but not focus). He, and his father, Iwan, were awarded an Academy Award in 1979 for the invention of the Moviola.

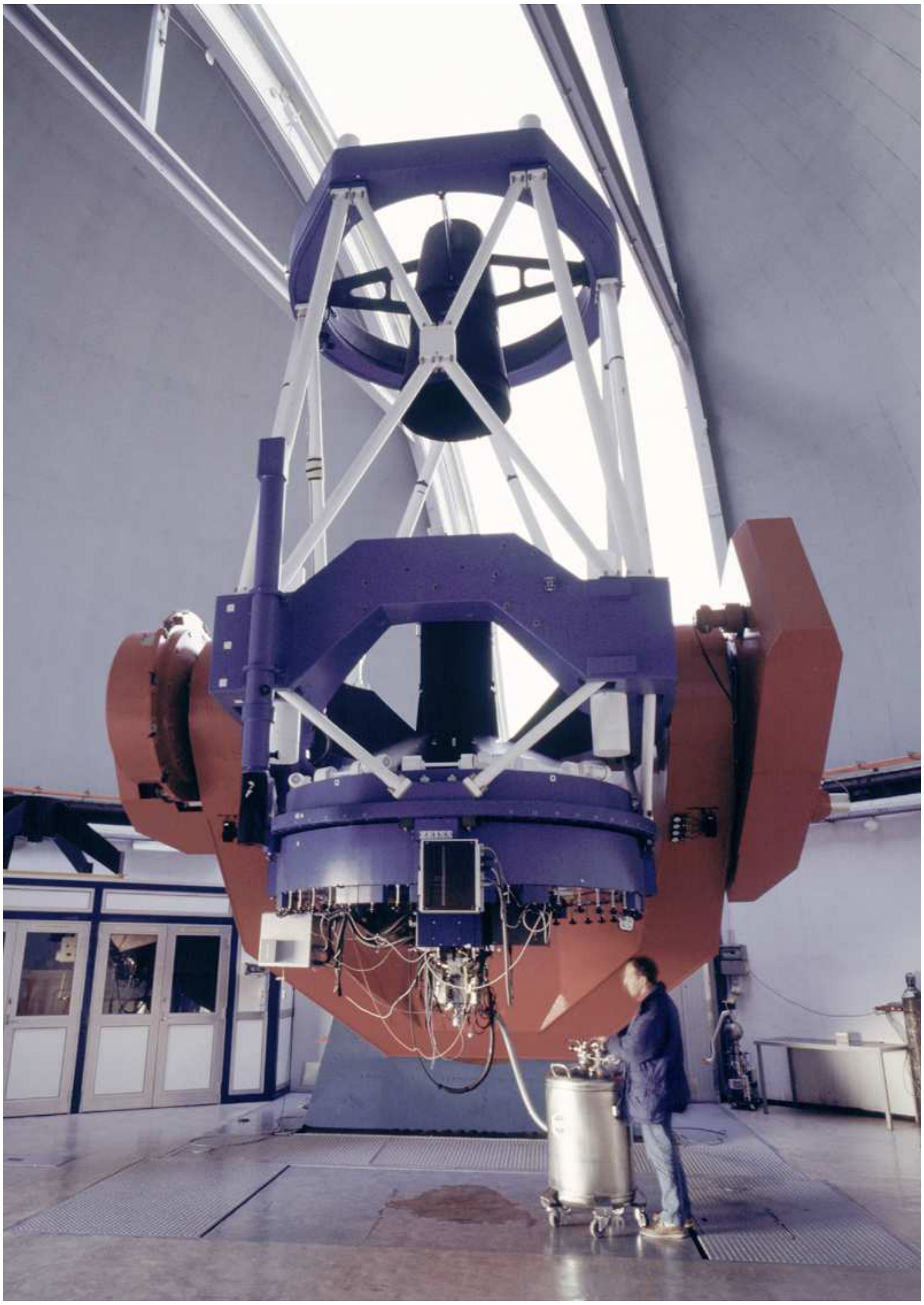


Figure 2.1: The 2.2-m telescope with WFI mounted at the Cassegrain focus.

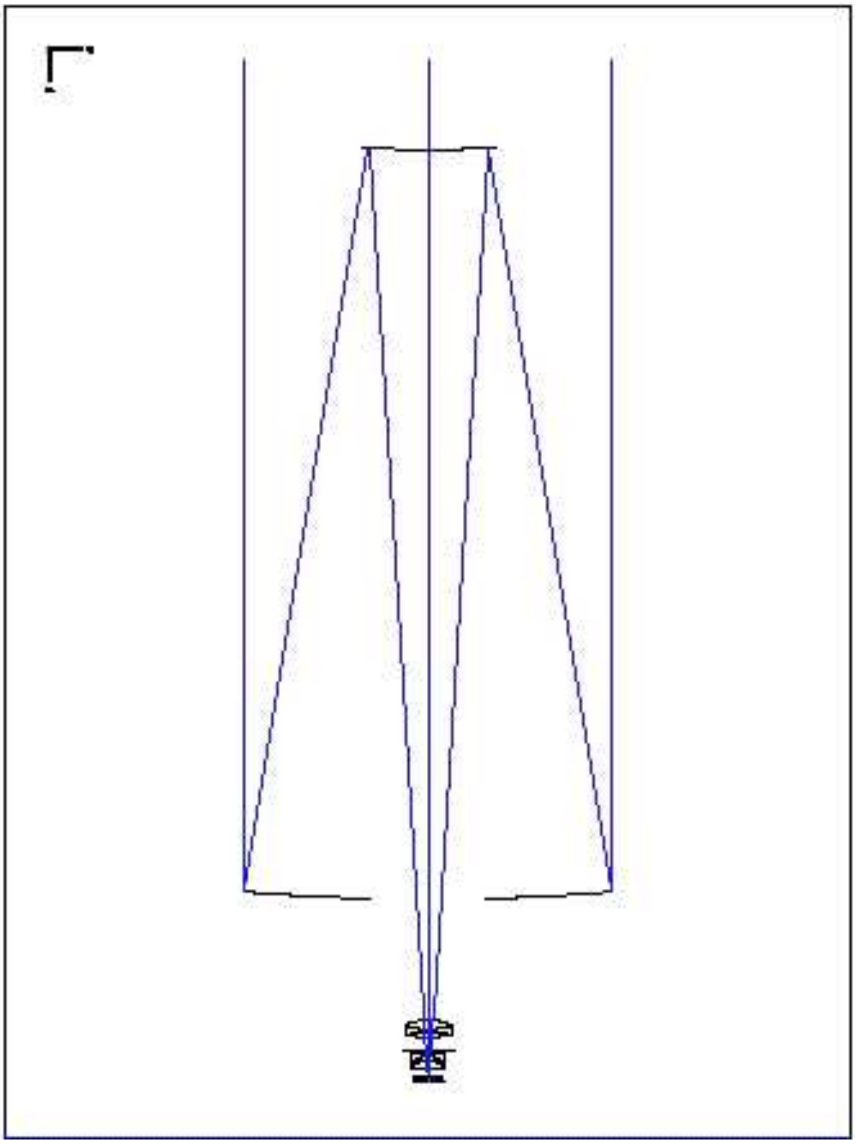


Figure 2.2: The 2.2-m telescope optical layout.

2.1.1 Pointing and tracking

The primary pointing model is established for a reference pixel on the tracker CCD with which the measurements are made. However, for normal observations, offsets are automatically applied so that the field center specified appears on chip "f", at the pixel (4150, 3950), about 32″ east and 42″ south of the center of the mosaic, nominally at pixel (4284,4128) (see Figure 2.5).

The pointing model provides an accuracy of $\sim$10″(rms) over the range from 0 to 60°in zenith distance. Offsets up to 3 arcmin have an absolute accuracy of $\pm$0.″5 and are reproducible to within $\pm$0.″2.

Pointing limitations: The zenith distance must be lower than 70°. (But note that at so large zenith distances pointing and tracking are inferior).

Free tracking quality: There is periodic error in the alpha drive mechanics with a period of 240 sec and peak-to-peak amplitude of 1.″2. Over 16 minutes, i.e. a multiple of this period, the free tracking was measured to be accurate to slightly more than 1″. Usage of the autoguider (Sect. 2.1.2.2) improves the performance to better than 0.″1.

2.1.2 Autoguider

The sub-system used for guiding is the *tracker* CCD chip of the detector system of WFI. As such it should in principle be discussed in that section. Nevertheless, because logically the system is part of the Telescope Control System (TCS), we will describe it here.

2.1.2.1 The tracker chip

On the eastern side (on the sky) of the science mosaic, there is one additional 2k $\times$ 4k detector (cf. Fig. 2.4 and Fig. 2.3). It is of the same type as the science CCD's but the lower two thirds of the $\sim$500 columns farthest from the mosaic are strongly compromised by numerous cosmetic defects. The practical impact is low, though, because this part of the chip is also the strongest vignetted by the mount of the camera optics (cf. Fig. 2.6). Further vignetting occurs on the side by the filter holder. The fully useful area is roughly banana-shaped and extends over columns Nos. 800-1880 (counted from the East) of the detector. If a bright enough guide star is available outside this central strip, it can be used without restriction. If a choice is possible, remember that differential atmospheric effects between guide star and mosaic are minimized when the distance (and the difference in airmass!) between the two is smallest.

This chip is illuminated by light that goes through a smaller rectangular filter adjacent to the main filter in the WFI filter holder (Fig. 2.6). Care has been taken in the choice of this filter so as to match the main filter pass-band. Nevertheless, these filters are broad-band glass filters, and, therefore, have a larger throughput than the interference filters so that narrow-band observations can use guide stars of the same magnitude as broad-band observations.

For autoguiding, a small sub-window of typically 50 $\times$ 50 pixels (maximum: 200 $\times$ 200) centered on the guide star is used. Because the tracker CCD and the science mosaic share the same shutter, the charges are, at a rate of 40,000 lines/s, very rapidly shifted towards the 'bottom' of the CCD until the window in question is fully hidden behind a mask, where it can no longer be contaminated by light. The high speed also ensures negligible trailing of the images. Once under the mask, the window is read out at a speed yielding suitable noise

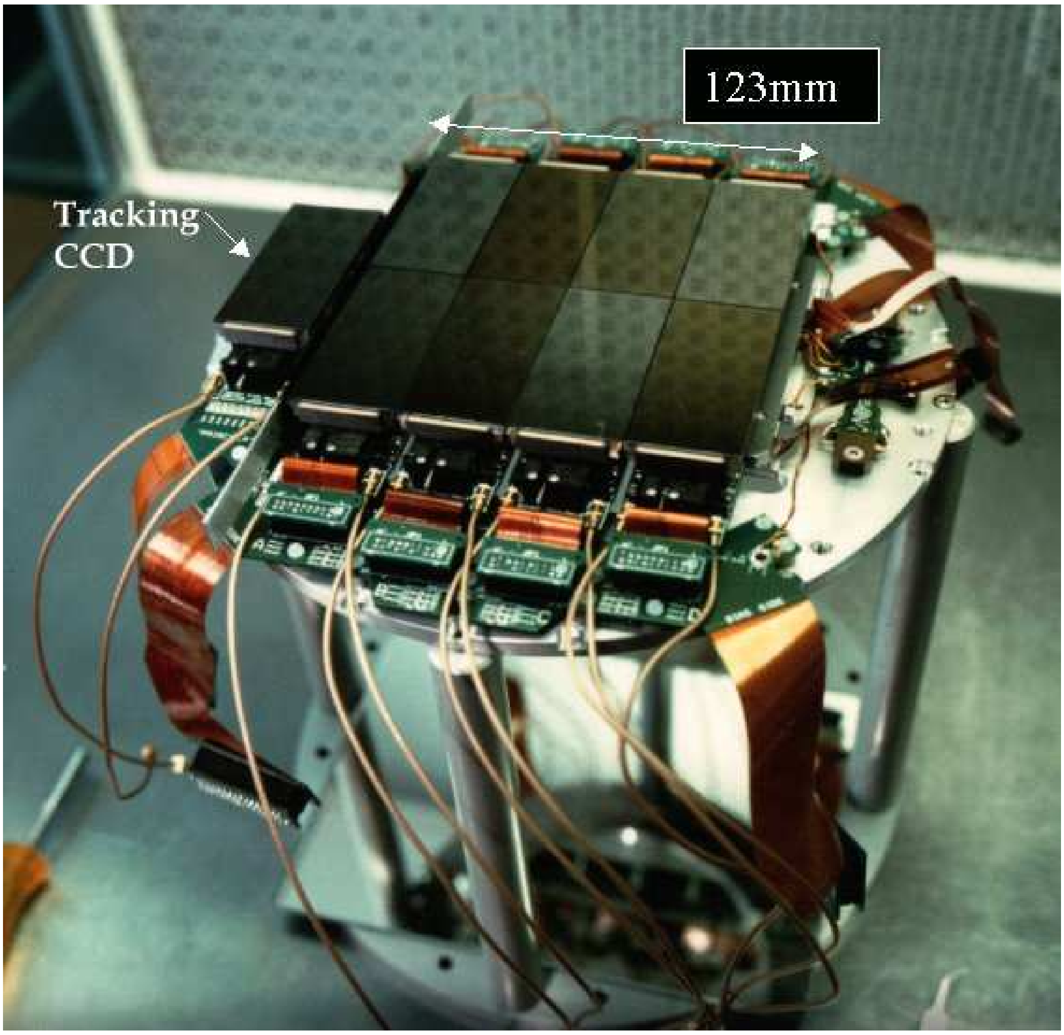


Figure 2.3: Image of the WFI detectors indentifying the tracker chip.

characteristics. The maximum rate is about 1 Hz. The default integration time is 2 seconds. For fainter stars it can be increased. However, because of the periodic 240-sec error of the telescope's alpha drive (Sect. 2.1.1), it is not advisable to user longer integration times than necessary.

For guide star acquisition purposes, acquisition exposures can also be made. In this mode, the full CCD is read out within $\sim$15 s; the image cannot be saved to disk.

A baffle between tracker chip and science mosaic shields the latter against stray light from bright guide stars (but see Sect. 2.4).

2.1.2.2 Autoguiding

Autoguiding is only done in (and only requires) a small window of the tracker CCD. Only for the selection or for the confirmation of the identification of a guide star is the full frame displayed on a separate incarnation of the Real Time Display (Sect. 2.9). It is not necessary to select guide stars in advance as this is done in real time at the telescope. These steps are performed by the telescope operator.

When the telescope is offset in order to cover the gaps between the CCD's in the mosaic, the window on the tracker CCD can be automatically offset by the same amount so that autoguiding can continue with re-identification of the guide star. This is known as combined offsets.

The autoguider can also be used to monitor the telescope tracking and *variations* of the point spread function (PSF) and the sky transparency. A corresponding graphical display is available. Note that the FWHM is *not* representative of the absolute image quality in the mosaic because the tracker CCD is rather far from the plane of the latter so that guide star images are significantly out of focus when the telescope is properly focused on the mosaic. Moreover, the imaging quality of the auxiliary filters is quite limited.

Because guide stars have a range of colours and they are observed through different filters, only an approximate limiting magnitude can be given above which stars can no longer be used for autoguiding. It is around 16-17 mag. Note that this limit depends on sky brightness, seeing, integration time, and wavelength. Normally, there is not even at high Galactic latitudes a problem to find a guide star of sufficient brightness, especially if the degree of freedom afforded by the wide FOV is exploited to slightly offset the telescope from the nominal coordinates.

Since tracker CCD and science mosaic share the same shutter, the shutter is briefly closed after autoguiding has started, and the CCD's of the mosaic are wiped a few times. Then, the shutter opens again, the science exposure starts, and autoguiding is resumed. All this is taken care of automatically by the TCS and OS and, therefore, completely transparent to the user.

Differential autoguiding over distances not exceeding the useful field of view of the tracker CCD is fully supported.

2.1.3 Focusing telescope and instrument

The whole process of focusing the telescope is transparent to the user. Nevertheless, it was felt important to explain some of the details of this critical procedure aspect for an imaging instrument. As with the guiding subsystem, the focusing subsystem is both part of the instrument and of the TCS, and will be described here.

Focusing is accomplished by moving the secondary mirror of the telescope. A focus sequence can be invoked via BOB (Chap. 5). It consists of a number of exposures with different focal positions between which the charges on the CCD are shifted by a constant amount. The CCD is read out only at the end of the sequence. It is recommended to use at least 8 focus positions with a step size of 40-50 M2 encoder units and to shift the subimages by 50 CCD pixels. Even when some stars may be bright enough for very short exposures, do not use an exposure time of less than 15-20 seconds because only then is atmospheric image motion properly averaged out. Since the mosaic is fairly co-planar with the focal plane, only the CCD in position #51 of the mosaic (Fig. 2.6) is used in order to save time and disk space.

Although this may take a little bit of extra time, the periodic 240-second error in the telescope drive (Sect. 2.1.1) makes it advisable to use the autoguider also for the short exposures of a focus sequence.

The central focus position of the sequence is automatically chosen using the formula (in M2 encoder units, valid near the zenith)

$$\text{focus}(T) = 25283 + \text{filterOffset} + \text{grismOffset} - 66 \times T$$

where the filter offset is a number that depends on the filter, and ranges between approximately 0 and -230; the grism offset is approximately 861 eu for the R50 grism; and where T is the temperature (in degrees centigrade) of the telescope's long Serrurier struts. It is displayed and continually updated in the TCS control panel. The focus value is expressed in units of steps of the M2 encoder, one encoder step corresponding to 1.25 μm. The proportionality factor is negative because M2 has to move towards M1 in order to compensate a thermal expansion of the Serrurier. There is an additional dependency of the focus on telescope position. Under good seeing conditions, a dedicated focus exposure should be done if the zenith distance between the science exposure and the last focus differ by more than 30°.

A MIDAS procedure, called from a focus Observation Block (OB, Chap. 5) is used by the operator to fit a parabola to the variation of the FWHM of point sources with focus position in order to determine the best focus. Since also the peak flux values are displayed, it is possible to check that no subimage was saturated, i.e. reached a value of 65,535. When the autoguider has been used, the focus curves displayed for both x and y should coincide extremely well. Under reasonable observing conditions, the focus values returned for different stars in the same exposure should not scatter by more than 3-5 encoder units.

The depth of focus is about 50 M2 encoder units. Remember (Sect. 2.2.2) that the residual tilt of the CCD mosaic with respect to the focal plane amounts to less than 15 encoder units to which up to 20 encoder units need to be added for the position-dependent instrument flexure.

The focus needs to be checked (or adjusted according to the above formula) whenever the change in temperature since the last setting of the focus exceeds half a degree. This is done automatically by the observing software.

Because the filters are in the converging beam, they have some optical power. Each filter is characterized by a focus offset with respect to the B/99 filter. The system automatically considers Serrurier temperature, telescope position, and filter offset, to determine the best focus before each science exposure. Nevertheless, **the system can not refocus the telescope during a single integration, therefore observers are advised to keep individual exposure integration time short.**

2.1.3.1 Finder telescope

Because of the large field of view of the instrument and the short read-out time of less than 30 seconds, remote access from the control room to a finder telescope is not offered. Nevertheless, one is available and it is sometimes used for the determination of a rough pointing model of the telescope.

2.2 The detector system and CCDs

The Wide Field Imager in a Nutshell

Field of view:	**(34×33) arcmin^2**
Pixel scale:	**0.238 arcsec/pixel**
Detector:	**4x2 mosaic of 2k $\times$ 4k CCD's**
Filling factor:	**95.9%**
Read-out time:	**27 seconds**
Read-out noise:	**4.5$\pm$0.1 e$^-$/pixel**
(Inverse) gain:	**2.0$\pm$0.1 e$-$/ADU**
Dynamical range:	**16 bit**
Saturation limit:	**$>$ 200.000 e$^-$/pixel**
Dark current:	**(0.3-0.6)$\times$10^{-3} ADU/s/pixel**
Max. pixel value:	**65,535 ADU**
Instrument F ratio	**5.9**
Peak overall througput:	**65.7 % at 501 nm**
Useful wavelength range:	**atmospheric cutoff through 1 μm**
Limiting magnitude:	**V $= 25.2$ mag (5σ det., in 60 min. at 1$''$seeing, and X=1.2)**
Overall intrinsic image quality:	**0.4 arcsec**
Overall geometrical distortions:	**$\leq$0.08%**
No. of simult. mountable filters:	**50**
Slitless spectroscopy:	**4.4 nm resolution at 420-900 nm (R50)**
Raw data format:	**FITS (with extensions), 142 Mbyte/file**
Overall mosaic dimensions	**8568$\times$8256**
Pixel to which pointing refers	**(4150,3950) in chip #56**

Figures 2.4 and 2.3 show the layout of the CCDs on the focal plane as well as its projection onto the filter plane. Note that the tracker chip, indicated with an arrow in Figure 2.3, and the main mosaic both sit behind the same shutter. This last property implies that it is not possible to pause an exposure and then restart it: if we were to do this the telescope tracking inaccuracies accumulated during the pause would become apparent once we open the shutter again.

The physical layout and dimensions are detailed in Figure 2.5 which gives the dimensions of the gaps together with the dimensions of the light sensitive areas (in white). The dimensions of the light sensitive areas, 2046x4128 where chosen as to permit binning 2x2 and 3x3. For details see the web pages of ODT at http://www.ls.eso.org.

Figure 2.6 shows an schematic view of the detector layout as projected onto the filter plane. The thin rectangles show the CCDs in the mosaic and the tracker CCD, respectively in the *detector plane.* Because the filters are in the converging beam, the mosaic projects in the *filter plane* onto the thick (outer) square. In the case of medium and narrow band filters, their dimensions closely match the thick square. The dashed rectangle corresponds to the auxiliary glass filter used for autoguiding. The large (inner) thin and (outer) thick circles delineate the limits of the optical field of view in the detector and filter planes, respectively. In the filter plane, point sources reach the dimensions of the small thick circles. As can be seen, stars falling right onto a corner of the mosaic are just not vignetted. By contrast, the two small circles at the position of the tracker CCD indicate the two most extreme positions between which there is essentially no vignetting. All other parts of the

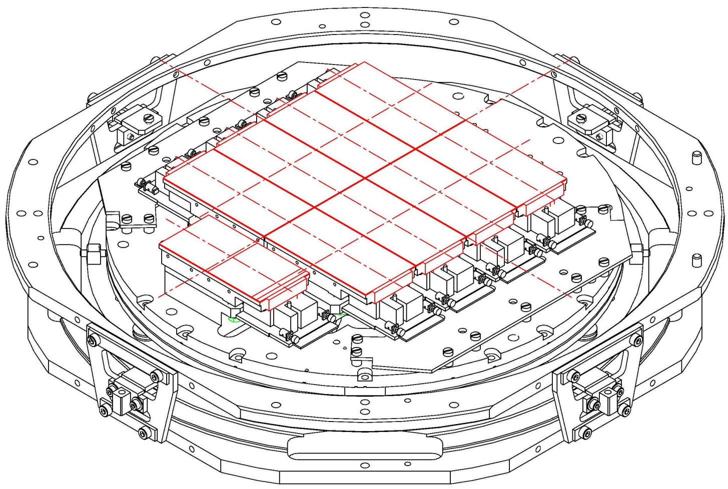


Figure 2.4: Schematic view of the WFI detector plane.

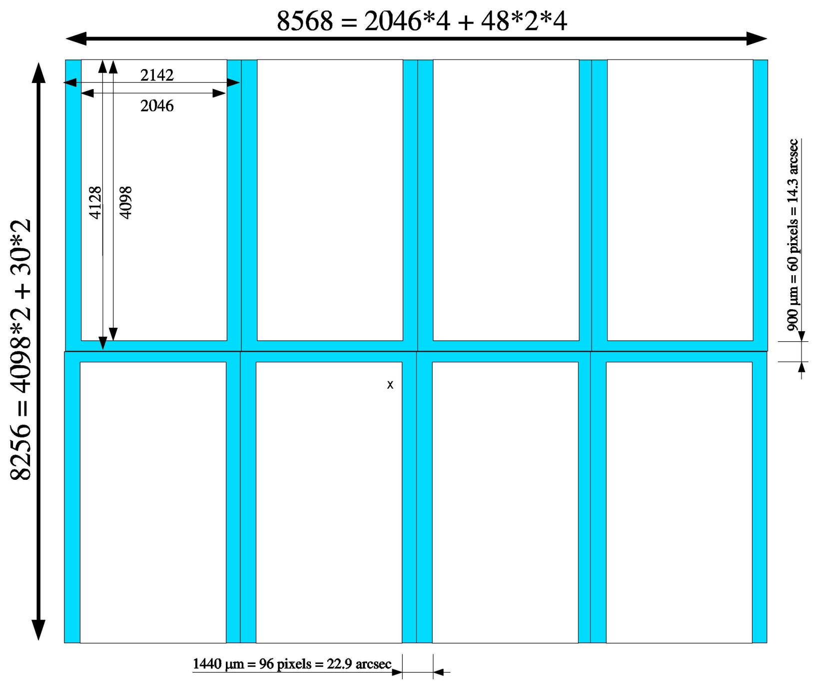


Figure 2.5: Physical layout of the WFI mosaic. The "x" on the bottom CCD second from the left marks the center of pointing in pixel (4150,3950).

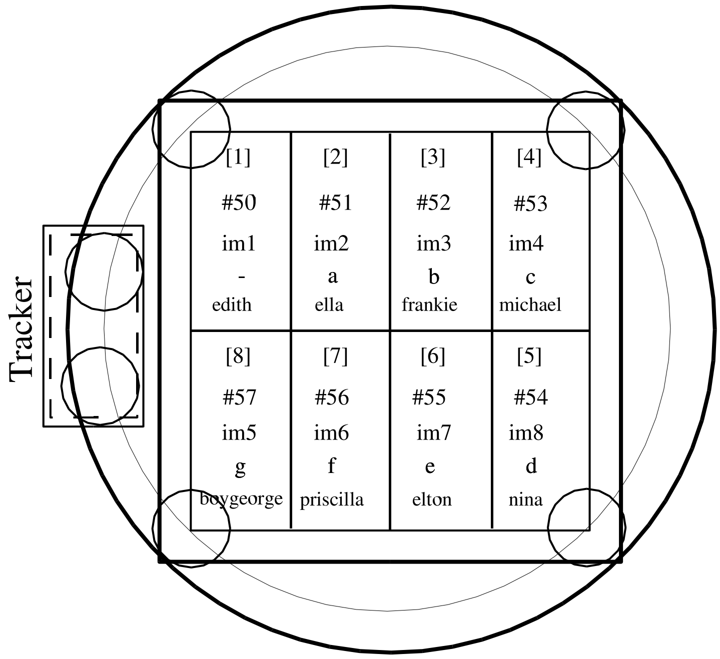


Figure 2.6: Schematic projection of the detector plane onto the filter plane, showing the vignetted areas. North is up and East to the left.

tracker CCD are more or less vignetted but, depending on the brightness of the star, still useful for autoguiding (in practice only for observations in narrow band filters or in Z and U, near the south galactic pole there are troubles, at times, to find a suitable guide star). Two of the broad band filters (Rc and I/lwp) are circular in shape and have the diameter of the outer (thick) circle and therefore cover both the mosaic and the tracker CCD. The cardinal directions are indicated as projected onto the sky. Note also the many identification schemes for the CCDs: (1) the number in brackets, e.g. [1], show the order in which the frames are stored in the Multi-Extension FITS files, MEF files, used to save the data[2]; (2) the #50 to #57 show ESO's ODT numbering for each of the CCD chips; (3) im1 to im8 is the numbering scheme used by IRAF MSCRED package; (4) the letters, and the "-" symbol correspond to the scheme used by MIDAS—the letters are appended to the root file name when they are read by the commands INTAPE/FITS or INDISK/FITS; and (5) the names corresponds to the scheme once used by ODT. To further complicate things each extension has a set of two identification keywords. The first is EXTNAME which have the values WIN1.CHIP1.OUT1, WIN1.CHIP2.OUT1, WIN1.CHIP3.OUT1, WIN1.CHIP4.OUT1, WIN1.CHIP8.OUT1, WIN1.CHIP7.OUT1, WIN1.CHIP6.OUT1, and WIN1.CHIP5.OUT2. The second is the keyword HIERARCH ESO DET CHIPi ID, with the string values 'ccd50' to 'ccd57'.

[2]Currently chips #50 to #57 are stored sequentially. This order can change at any moment and any software writen to reduce WFI data should not assume that the chips will have this order within the MEF file and use instead the identification keywords in the extension headers.

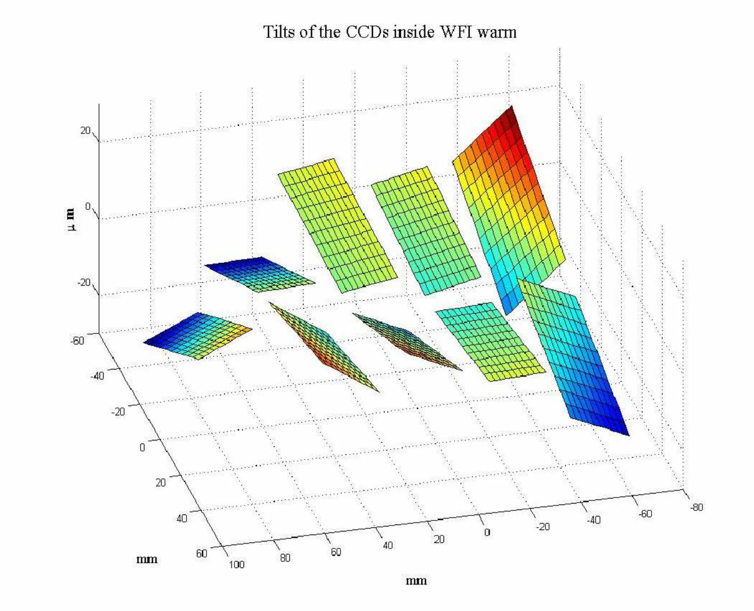


Figure 2.7: The 3D positioning of the WFI chips on the detector plane.

Figure 2.7 gives the relative positions of the chips, showing their tilts as measured by ODT at room temperature. This last figure shows that some systematic variations in focus and PSF can be expected in a chip-by-chip basis.

2.2.1 The FIERA CCD controller

All scientific CCDs at ESO are controlled by the **F**ast **I**mager **E**lectronic **R**eadout **A**ssembly, FIERA. It was designed with the requirement that it should have negligible system noise relative to the CCD noise, to be linear to better than 0.5% over the dynamic range of the A/D converter, to have no pattern noise, and to have cross-talk between the video channels which is less than 1 part in 100,000 (for 16 bit A/D converters).

Figure 2.8 shows the five sub-systems of FIERA:

1. Embedded computer, with auxiliary boards for sequence timing, data capture and network connection to other computers.

2. Detector head electronics, with clock drivers, analogue bias generation, and video signal processing.

3. CCD detector head, with pre-amplifier circuitry.

4. PULPO house keeping box for temperature control, vacuum sensing, and shutter control.

5. DC power supply module to generate the 5, $\pm$15, 24 and 30 volts DC power needed by the detector head electronics and PULPO.

The components represented by the three top boxes of Figure 2.8 are in the computer room, at the ground floor of the 2.2-m telescope, while the bottom components are attached to the telescope. They are attached by a giga-bit fiber link, as depicted in the figure.

Note that small size and low power consumption was not part of the design requirements. As a result FIERA needs to use liquid cooling to keep the heat input into the dome under control. Figure 2.1 show the rubber-insulated hoses of the cooling system of FIERA.

FIERA receives commands or queries from the instrument software and deliver replies or FITS images to the instrument workstation. FIERA software uses the real time display module, RTD, to display images as they are read. The RTD provides most of the requirement for quick look and analysis of the incoming images. Figure 2.9 shows an image displayed with the RTD, together with the 'Pick Object' window which permits the determination of FWHM and position angle of stellar images. Note that the FWHMs are those of the stellar minor and major axes.

2.2.2 Basic CCD mosaic characteristics

As mentioned before, the detector system for scientific exposures is an array of 2×4 *CCD44* chips by EEV which have $2k \times 4k$ 15-μm pixels each. They are three-side buttable; with gaps of $\sim$ 98$\pm$2 pixels along the long and of $\sim$30$\pm$2 pixels along the short side of the chips (Fig. 2.5).

In order that on-chip binning (cf. below) yields consistent results for all binning factors supported, the actual *number of light-sensitive pixels* per chip is 2046 in the horizontal (East-West) and 4098 in the serial (Nort-South) direction. In addition, there are 48 pre- and also 48 overscan pixels in the horizontal direction and 30 vertical overscan pixels which can be used for monitoring the bias level. The mosaic, therefore, comprises 8184×8196 = 67,076,064 light-sensitive pixels and subtends an angle of roughly $0.57 \times 0.54 = 0.31$ square degrees, i.e. matches the largest possible square contained in the optical FOV (Sect. 2.6).

The surfaces of all 8 chips are confined between two planes $\sim$80 μm apart. The mean plane of the mosaic has been carefully aligned with the focal plane so that, if the focus is properly set, the peak-to-peak difference in optimal focus does not exceed 15 M2 encoder steps (Sect. 2.7) near the zenith. This is well within the focal depth of about 50 encoder units. At hour angles of $\pm$2.5 hours flexure adds up to another 25 encoder units to the above figure for the focal tilt of 15 encoder units.

The CCD's are notable for their high *quantum efficiency* from the atmospheric cut-off and through the visual part of the spectrum (Fig. 2.10). The QE reaches a maximum of approximately 95% at 500 nm, and have a useful range with $qe > 10\%$ between 350 and 950 nm. There are slight chip-to-chip variations which are probably due to differences in the effectiveness of the anti-reflection coating. Figure 2.10b shows the difference in qe with respect to the mean curve for the different detectors. We can see that in the UV the best chips are #54 and #56.

The *pixel response non-uniformity* (PRNU) depends on the wavelength because redder photons create electrons deeper within the CCD. Towards longer wavelengths, there is also some *fringing*. Some indicative figures are given in the following table:

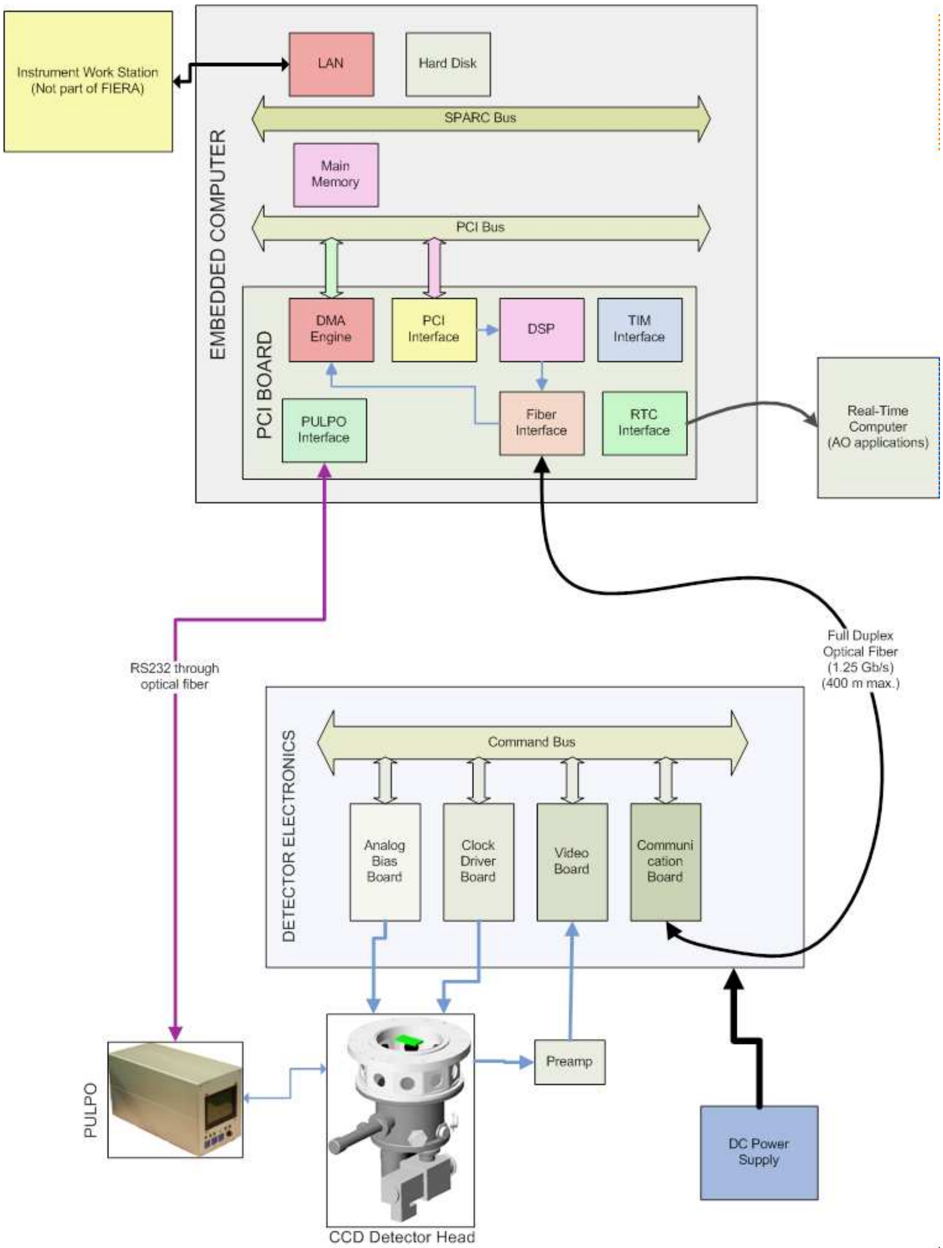


Figure 2.8: FIERA hardware architecture showing printed circuit boards of the embedded computer and the detector head electronic (from [5]).

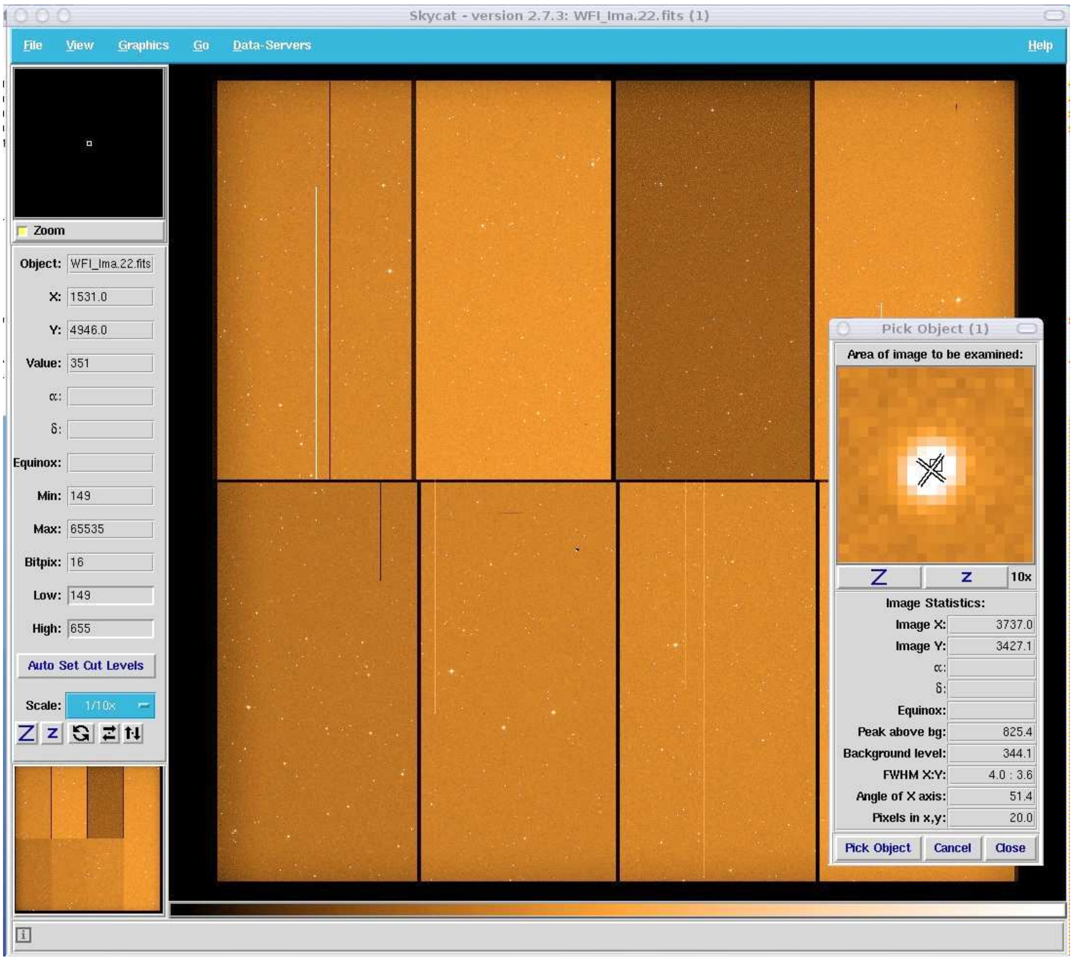


Figure 2.9: A WFI image being displayed with the RTD, together with the 'Pick Object' windows showing the centroid in pixel coordinates, and the FWHM of a star.

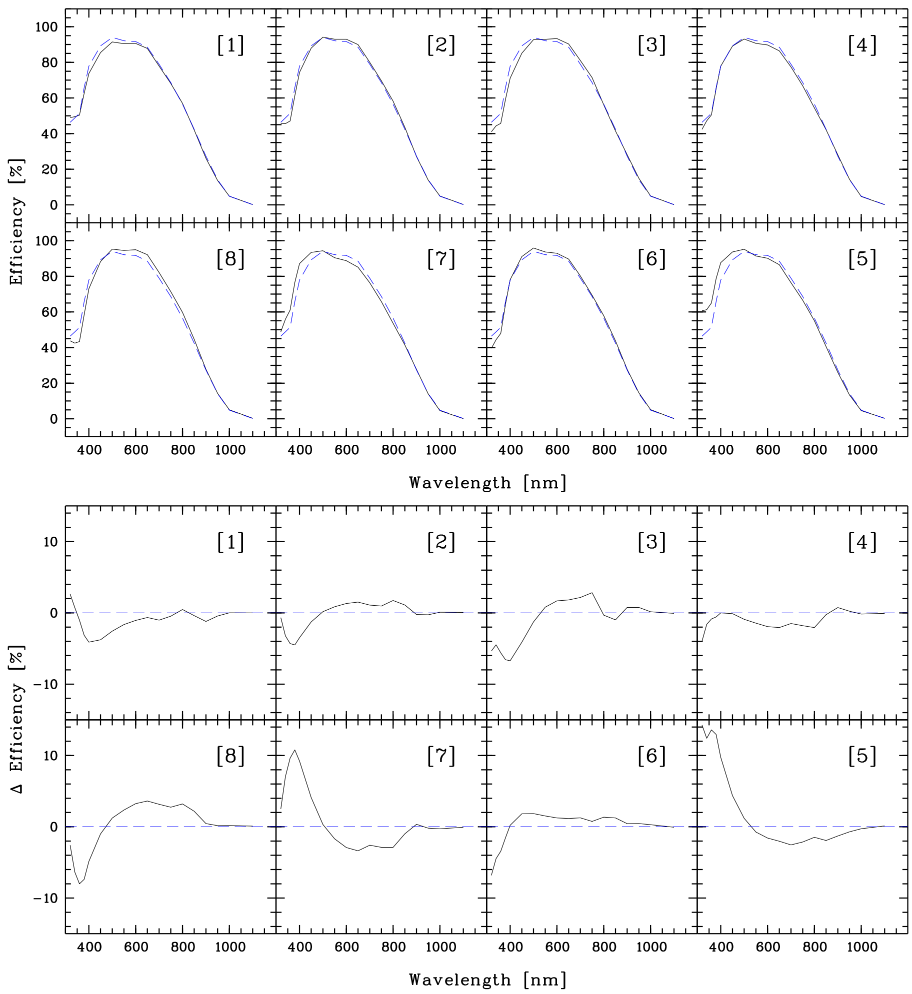


Figure 2.10: (a, top) Quantum efficiencies of the WFI CCDs together with the mean curve. (b, bottom) Difference with respect to the mean QE for each chip.

Wavelength nm	PRNU % rms
320	2.3
400	0.9
550	0.8
700	0.9
800	1.6
900	2.7
1000	7.0

Of the two readout ports per chip (in the mosaic they are on the 'outer' short sides - Fig. 2.5) only the one with the better noise characteristics is used. The readout ports are not selectable by the user. The readout speed is fixed at 357,000 pixels/port/s which corresponds to a *readout time* of 27 seconds. The overhead for the creation of the FITS file, the data transfer to the workstation, and the display on the Real Time Display together take another half minute. For most purposes, the *read noise* of around 5 e^-/pixel (cf. the following table) should be practically negligible in comparison with the photon shot noise of the sky background.

	CCD #50	CCD #51	CCD #52	CCD #53
Read noise [ADU]	2.3	2.3	2.1	2.3
Gain [e^-/ADU]	1.9	2.0	2.2	1.9
Read noise [e^-]	4.5	4.6	4.6	4.4
	CCD #57	CCD #56	CCD #55	CCD #54
Read noise [ADU]	2.1	2.2	2.4	2.4
Gain [e^-/ADU]	2.1	2.1	1.9	1.9
Read noise [e^-]	4.5	4.6	4.7	4.5

For instance, even during a dark night, a B-band exposure needs to be shorter than 2 minutes in order not to be sky-noise dominated. The exposure time calculator (Sect. 3.1) can be used for the evaluation of more specific cases. Upon readout, the data are written directly to the RTD (Sect. 2.2.1) for immediate inspection.

Note the good match between read noise and gain so that the contribution by the A/D conversion to the noise is negligible whereas the dynamical range of the CCD is optimally exploited.

The *charge transfer efficiency* is better than 0.999999 in both parallel and serial direction. This means that of the charges in the pixel diagonally opposite of the readout port (from where the charges have to be shifted the largest number of times before they reach the readout port) a fraction of $0.999999^{4098} * 0.999999^{2046} = 0.996$ still appears in exactly that pixel of the image. The remainder is smeared out to subsequent pixels.

The *dark signal* is hardly measurable and negligible for most application, typically $\sim$(0.3-0.6) $\times 10^{-3}$ ADU/sec/pixel.

The following *on-chip binning* patterns are supported: 1×1, 2×2, 3×3, 1×2, and 1×3. The latter two are intended to be used with spectroscopic applications (Sect. 4) if the spectral resolution is not to be reduced by binning. *Windowing* of the mosaic is not offered, i.e. only the entire mosaic can be read out. The only exception are focus exposures which only utilize chip #51 (Fig. 2.6).

2.2.3 Other properties

The *physical saturation limit* is more than 200,000 e^- per pixel. At the fixed inverse *gain factor*, which varies between 1.9 and 2.2 e^- from CCD to CCD (see table below), the 16-bit A/D converter provides a *dynamical range* up to roughly 130,000 e^-. Over this range, peak-to-peak deviations from *linearity* range from 0.2 to 0.8%, in the case of CCD #55 to 1.6% (Fig. 2.11). Currently available evidence suggests that the nonlinearity is extremely stable so that the data can be reliably corrected for it.

Strong overexposures lead to *charge overflow* ("blooming"). The number of vertically adjacent pixels affected by this depends on the overexposure factor with respect to the saturation level of the A/D converter at 130,000 e^-/pixel (physically, it is the overflow of the saturation limit of the pixel but directly measurable is only the saturation of the A/D converter) and the direction with respect to the readout port. The following table gives a crude indication of the order of magnitude for point sources. ℓ_1 denotes the number of pixels concerned towards the readout port, ℓ_2 the one in the opposite direction (note that on the southern group of CCD's [cf. Fig. 2.6] the ports are at the southern edge and on the northern group at the northern edge):

Direction	Overexposure factor							
	2	4	5.8	10	25	50	100	1000
ℓ_1 [pixels]	0	0	1	2	8	19	39	344
ℓ_2 [pixels]	0	0	1	3	5	8	13	136

Another side effect of strong saturation can be *signal remanence*. It is primarily due to electrons generated at the surface of the CCD where they are only weakly exposed to the electrical field applied to read the CCD. Since they can, therefore, only be removed after diffusion has let them drift into deeper layers, reading or wiping the CCD is not necessarily very effective to remove remnant charges. It is the diffusion time which sets the pace. However, the laboratory and commissioning test data described below to check for cross talk did not yield any detectable remnant signal in immediately subsequent (but short) dark exposures.

Because the CCD's in the mosaic share various components of the control electronic, it is, in principle, possible that some *cross talk* occurs as the result of which a strong signal in one CCD would lead to a weak "echo" in the data coming from one or more of the other CCD's. Laboratory measurements with only a single small light spot, which was integrated on such as to exceed the physical saturation limit by a considerable factor, showed a very weak measurable remnant signal only in very few combinations of exposed and not exposed CCD's. The level of this electronic ghost of less than 5 ADU's should for most practical purposes be negligible. In fact, 15-second integrations on an isolated 4th magnitude star did not detect any electronic ghosts at all.

Since there will often be bright stars in WFI fields, users may nevertheless wish to watch out for this effect. As it only occurs in case of heavy saturation, electronic ghosts can be easily distinguished from real objects by the presence also of the charge overflow pattern as in the real image. The readout timing of the mosaic would suggest that the most likely areas to be affected are those with the same pixel numbers *relative to the respective readout port*. That is, the different readout directions of the two rows of CCD's in the mosaic as well as the fact, that chip #57 is read out in the direction opposite to the other chips in that row, need

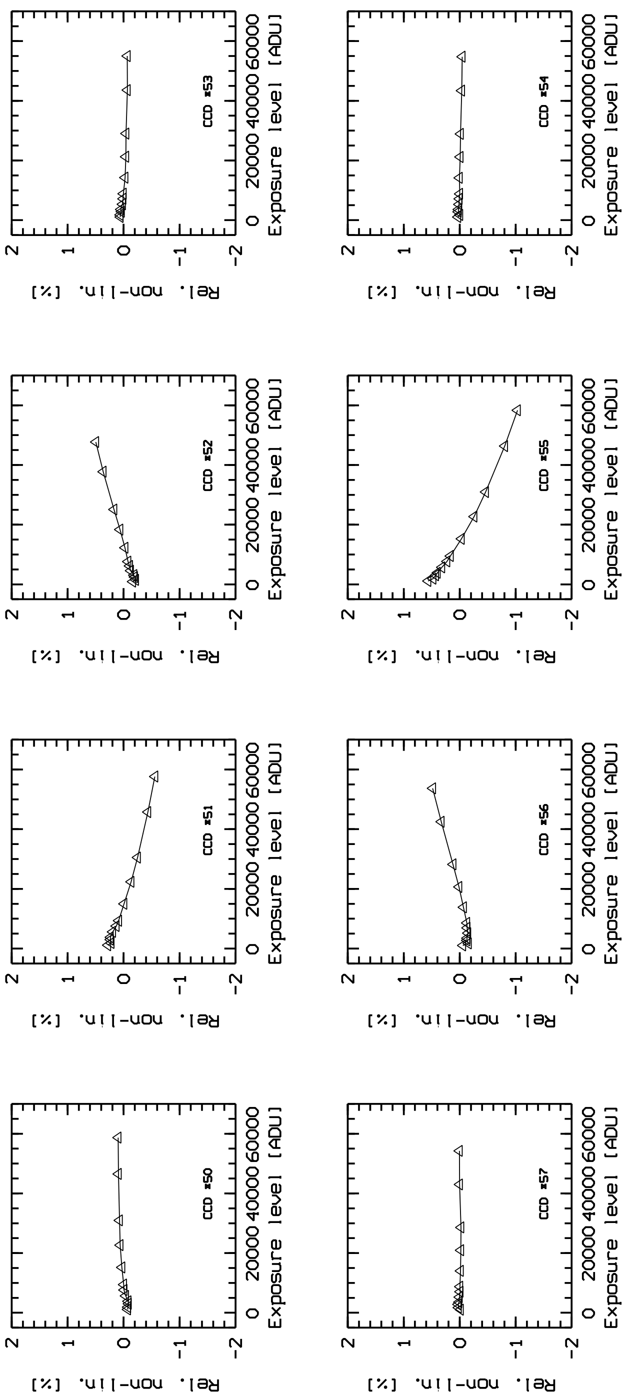


Figure 2.11: Deviation (in percent) from perfect linearity as a function of the exposure level. For instance, if an exposure with CCD #55 in some pixel reaches a level of 60,000 ADU, it is actually too low by about 600 ADU (i.e., by 1%).

to be kept in mind.

Tables 2.1 and 2.2 lists column numbers and their starting rows of all *hot and dark columns*, respectively. *Note* that, because of the opposite read-out direction, for chips #54 through #57 (cf. Fig. 2.6) defective columns extend from their starting point towards higher row numbers whereas for chips #50 - #53 they affect rows with lower numbers. *Note* further that, as a result of the photographic definition of the pixels through a mask of 1024×512 pixels, which is offset twice in the horizontal direction and in 8 steps along the other axis to cover the entire chip (this process is sometimes called 'stitching'), the central column and every 512th row appear in a flat field exposure either brighter or darker than the others. This is not a chip defect but simply due to such columns and rows being very slightly broader/narrower than the others so that they are exposed to more/less light than on average.

Other cosmetic defects are:

CCD #50: In the area between columns Nos. 900 through 1250 and rows Nos. 2930 to 3160, this CCD has a number of hot pixels. Most of them are aligned along an arc and are also the starting point of hot columns.

CCD #52: There is a scratch between columns Nos. 1560 and 1760 which extends from row No. 3770 to No. 4098.

CCD #56: Rows Nos. 3589, 3797-3707, and 3779-3781 are partly or over their length dark.

All CCD's: Numerous low-sensitivity pixels, both single and in small clusters. They flat-field out at a level of 0.5% or better.

The *charged-particle hit rate* at levels above 200 ADU's, where the contribution of imperfectly subtracted bad pixels becomes negligible, is between $0.15\,10^{-6}$ and $0.3\,10^{-6}$ pixel^{-1} sec^{-1}.

Further information incl. reports on the most recent tests can be found on the WWW pages of La Silla SciOps (URL: http://www.ls.eso.org/lasilla/sciops).

2.2.4 The shutter

Both the science mosaic (Sect. 2.2.2) and the tracker CCD (Sect. 2.1.2.1) share the same shutter. It consists of a rotating, roughly semi-circular disk. It can operate at two different speeds. In view of the large size of the shutter the faster speed is only used for exposures shorter than 2 seconds in order to reduce fatigue and wear of the mechanics. The selection of the shutter speed is done automatically by the control software and, therefore, completely transparent to the user.

From the ratio of short and long exposures taken both with a β-light and on the twilight sky, only an upper limit of 0.2% for the nonuniformity of the shutter motion could be determined. The shutter error is of the order of 0.034 sec, i.e. the actual shutter open time is on average 0.034 sec shorter than measured by the instrument itself and stated in the FITS header. After correction for this shutter error, there are still some systematic residual errors as shown in Fig. 2.12. Note that an error of 1% for an exposure time of 0.2 sec translates into an absolute error of only 2 msec which for a shutter of this size is excellent.

Table 2.1: Hot columns of the CCD's in the WFI mosaic.

Chip #50		Chip #51		Chip #52		Chip #53	
Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.
570	$\leq$2900	78	$\leq$2007	1088	$\leq$1214	80	$\leq$1575
659	$\leq$3402	137	$\leq$2044	1339	$\leq$2717	104	$\leq$1600
1013	$\leq$3036			1890	$\leq$2345	269	$\leq$1570
1014	$\leq$3036			1956	$\leq$2091	340	$\leq$1
1083	$\leq$3149			1987	$\leq$1295	341	$\leq$1
1084	$\leq$3049			2013	$\leq$2116	342	$\leq$1
						372	$\leq$1785
						374	$\leq$1760
						593	$\leq$3060
						631	$\leq$1
						644	$\leq$3060
						677	$\leq$1
						683	$\leq$1
						688	$\leq$2617
						719	$\leq$860
						720	$\leq$1622
						726	$\leq$2520
						731	$\leq$1892
						750	$\leq$1
						840	$\leq$1725
						849	$\leq$1337
						856	$\leq$1430
						880	$\leq$2361
						891	$\leq$2147
						903	$\leq$1555
						940	$\leq$1922
						956	$\leq$2131
						970	$\leq$814
						1138	$\leq$1223
						1715	$\leq$1190

Chip #57		Chip #56		Chip #55		Chip #54	
Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.
12	$\geq$2047	2	$\geq$1	50	$\geq$1056	1198	$\geq$927
76	$\geq$914	15	$\geq$1571	251	$\geq$1672	1259	$\geq$358
77	$\geq$914	19	$\geq$2124	335	$\geq$1		
144	$\geq$333	29	$\geq$1	507	$\geq$225		
154	$\geq$1693	46	$\geq$2255	765	$\geq$362		
219	$\geq$1756	65	$\geq$1706	903	$\geq$1		
288	$\geq$1762	75	$\geq$1461	1048	$\geq$229		
300	$\geq$510	131	$\geq$2036	1628	$\geq$994		
304	$\geq$1848	135	$\geq$1468	1766	$\geq$337		
469	$\geq$556	144	$\geq$1034				
1171	$\geq$1	146	$\geq$1571				
1495	$\geq$3312	193	$\geq$1				
		231	$\geq$2384				
		252	$\geq$2416				
		267	$\geq$1310				
		307	$\geq$15				
		320	$\geq$1				
		336	$\geq$1477				
		433	$\geq$1165				
		1316	$\geq$1561				

Row numbers denote where the defect starts (cf. Sect. 2.2.3); the "$\leq$" and "$\geq$" signs give the direction of the defect (*all* subsequent pixels in the given column are affected). Column and row numbers are counted starting with the first southeastern ligh-sensitive pixel of each CCD. The numbers have been compiled carefully but can only be regarded as indicative.

Table 2.2: Dark columns of the CCD's in the WFI mosaic.

Chip #50		Chip #51		Chip #52		Chip #53	
Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.
1147	$\leq$1						
1148	$\leq$1						
1149	$\leq$1						
1150	$\leq$1						
1151	$\leq$1						
1152	$\leq$1						
1153	$\leq$1						
1154	$\leq$1						
1155	$\leq$1						
1156	$\leq$1						
Chip #57		Chip #56		Chip #55		Chip #54	
Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.	Col. No.	Row No.
707	$\geq$2435	682	$\geq$1899	1261	$\geq$479	257	$\geq$862
708	$\geq$2435	948	$\geq$1848			1068	$\geq$3772
1663	$\geq$3084	1931	$\geq$2962			1069	$\geq$3772
						1553	$\geq$ 807
						1690	$\geq$3346
						1691	$\geq$3346

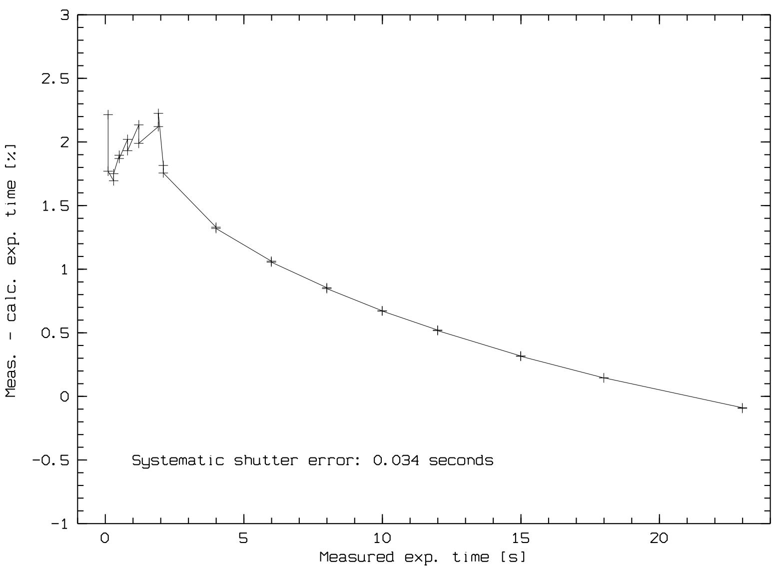


Figure 2.12: The fractional difference (in percent) between (i) the computed (by means of a linear regression analysis) shutter open time and (ii) the one measured by the instrument electronics plotted versus exposure time. From the difference the systematic error of 0.034 sec is already subtracted. The exposure time in the FITS headers is the measured one and, therefore, has to be corrected for both the systematic error, which is independent of the exposure time, and the fractional error shown in the graph. The small discontinuity around exposure times of 2 seconds is due to the change-over between the two shutter speeds.

2.2.5 Data format

The data is saved in a multi-extension FITS file, MEF file, following the standard as set forth in the document *Definition of the Flexible Image Transport System (FITS)*, prepared by the NASA/Science Office of Standards and Technology, NOST, in their document NOST 100-2.0[14]. A WFI file consists of a Primary Header and Data Unit, HDU, without any data, followed by 8 conforming extensions, one for each CCD, with their own HDU. For an important note on the order of the chips within a MEF file see the footnote in page 31. The minimum unit of headers and data are *records* of 36 *card images* each. The card images in turn consist of 80 bytes (8-bit) each. The detailed byte balance of an MEF file can be seen in Table 2.3, where we can see that a full MEF file weights 60,480 + 8×(5,760 + 17,686,080) bytes, or 141,595,200 bytes, of which 8×2×864 are unused.

Table 2.3: Byte balance of an WFI MEF image file.

		Primary HDUs
Header	=	21 records
	=	21×(36 card images)
	=	60480 bytes
		8 extensions HDUs
X-tension Header	=	2 records
	=	2×(36 card images)
	=	5760 bytes
X-tension Data	=	6141 records
	=	17,686,080 bytes
	=	(2142×4128 + 864) pixels × 2 bytes/pixel

2.2.6 The WFI image headers

The arrangement of the different detectors in the mosaic is described using standard FITS keywords which are defined in the NOST document. Fig. 2.13 show the relevant page of ESO's *Data Interface Control Document* [9] which explicitly deals with the positional keywords.

According to this document each extension header should contain the keywords CRTYPE1, CRTYPE2, CRVAL1, CRVAL2, CRPIX1, and CRPIX2. Furthermore, the keywords CRTYPE1 and CRTYPE2 should be 'PIXEL" in all the extensions, and the keywords CRVAL1 and CRVAL2 should have the same value in all extensions, 4284, and 4128 respectively, the nominal center of the mosaic.

Figure 2.14 show the actual keywords present in each of the extensions. According to the extension headers the reference pixel coincides with the bottom left corner, on-sky pixel, of chip [8], and *not the central mosaic pixel* (center of rotation of adapter). The extension headers assume that all the top row chips are perfectly aligned in the vertical direction with CRPIX2=-4097 for all of them; for the bottom row of chips a similar assumption is made with CRPIX2=1.0 for all chips. Furthermore, the headers also assume that the two chips of a given column are also aligned: chips #50 and #57 with CRPIX1=49, chips #51 and #56

Keyword Description

Note that coordinates in FITS frames refer to the center of pixels, i.e. pixel 1 would integrate flux between 0.5 and 1.5 if the chip had uniform sensitivity.

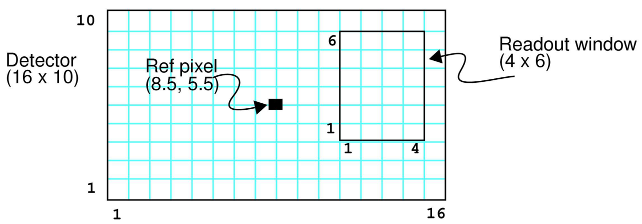
TABLE 3 Usage of coordinate system keywords for raw frames

	Keyword	Example	Explanation
(R)	**CRVAL1**	**1020.**	X Ref. pixel of center of rotation
(R)	**CRVAL2**	**1025.**	Y Ref. pixel of center of rotation
(R)	**CRPIX1**	**315.**	Value of X ref pixel
(R)	**CRPIX2**	**325.**	Value of Y ref pixel
(R)	**CD1_1**	**1.00000**	1 image pixel per detector pixel
(R)	**CD2_1**	**0.00000**	no rotation, no skew
(R)	**CD1_2**	**0.00000**	no rotation, no skew
(R)	**CD2_2**	**1.00000**	1 image pixel per detector pixel
(S)	**CTYPE1**	**'PIXEL '**	Pixel coordinate system
(S)	**CTYPE2**	**'PIXEL '**	Pixel coordinate system

CRVALn give the reference pixel of the full detector matrix.

GUIDELINE–12 The reference pixel is defined as the pixel (possibly with fraction if the accuracy is achieved) through which the center of rotation of the adapter intersects the detector.

CRPIXn give the position of the reference pixel of the detector matrix (**CRVALn**) relative to the coordinate frame of the readout window. The following picture illustrates the use of **CRVALn** and **CRPIXn** for a window readout:



when the complete detector is readout **CRPIX1**/**CRPIX2** are equal to **CRVAL1**/**CRVAL2**, i.e. 8.5 and 5.5 respectively. In the case a window only is readout, **CRPIX1 = -3.5** and **CRPIX2 = 2.5** while **CRVAL1**/**CRVAL2** remain the same.

CDn_m give the elements of the coordinate translation matrix. For a detector coordinate system no rotation is applied, hence the non-diagonal elements of the matrix are 0. **CD1_1** and **CD2_2** give the number of detector pixels per data pixel in x- and y-direction, respectively. They are also known as the binning factors. These keywords replace **CDELTn** and **CROTAn**, the use of which is deprecated.

CTYPEn gives the coordinate system for **CRPIXn**. **CTYPEn** for raw frames is the string **'PIXEL'** indicating that coordinate system refers to detector pixels.

Figure 2.13: Extract from page 21 of ESO's DICB document [9].

with CRPIX1=-1997, chips #52 and #55 with CRPIX1=-4043, and chips #53 and #54 with CRPIX1=-6089.

The RA and DEC keywords in the headers should refer to the above reference pixels if we want to use these keywords to determine approximate RA and DEC for the objects in the images. They don't, instead the RA and DEC keywords are referred to pixel 4150, 3950 (with an accuracy of $\pm 10''$, the accuracy of the pointing model of the telescope). To recover the ability to do approximate astrometry the keywords need to be modified: CRPIX1→CRPIX1+(4150-49), and CRPIX2→CRPIX2+(3950-1), and proper CDi_j keywords should be added. This is explained in Chapter 7.

Notice that following each extension header the data is store using two bytes per per pixel (BITPIX=16), in big-endian byte ordering, the standard in FITS (notice that x86 machines use little-endian ordering, while power-pc use big-endian), with a non-zero BZERO keyword. The data is stored line-by-line, with the first pixel being the lower-left hand corner one in all extensions, with lines increasing from bottom to top.

Because the output amplifier is at the top left corner for all the top row of chips, the pre-scan pixels do correspond indeed to the first 48 pixels, and the over-scan pixels correspond to the last 48 pixels of a given line. For the bottom row of chips the situation is more complex: chip #57 is read using an amplifier at the bottom-left, thus the pre-scan and over-scan pixels correspond also to the first and last 48 pixels respectively; while for chips #54, #55, and #56 the pre-scan pixels are the last 48 in a given row, and the over-scan pixels are the first 48. Notice that all but chip #57 are read with what the manufacturer calls the 'L' amplifier. Chip #57 is read with the 'R' amplifier.

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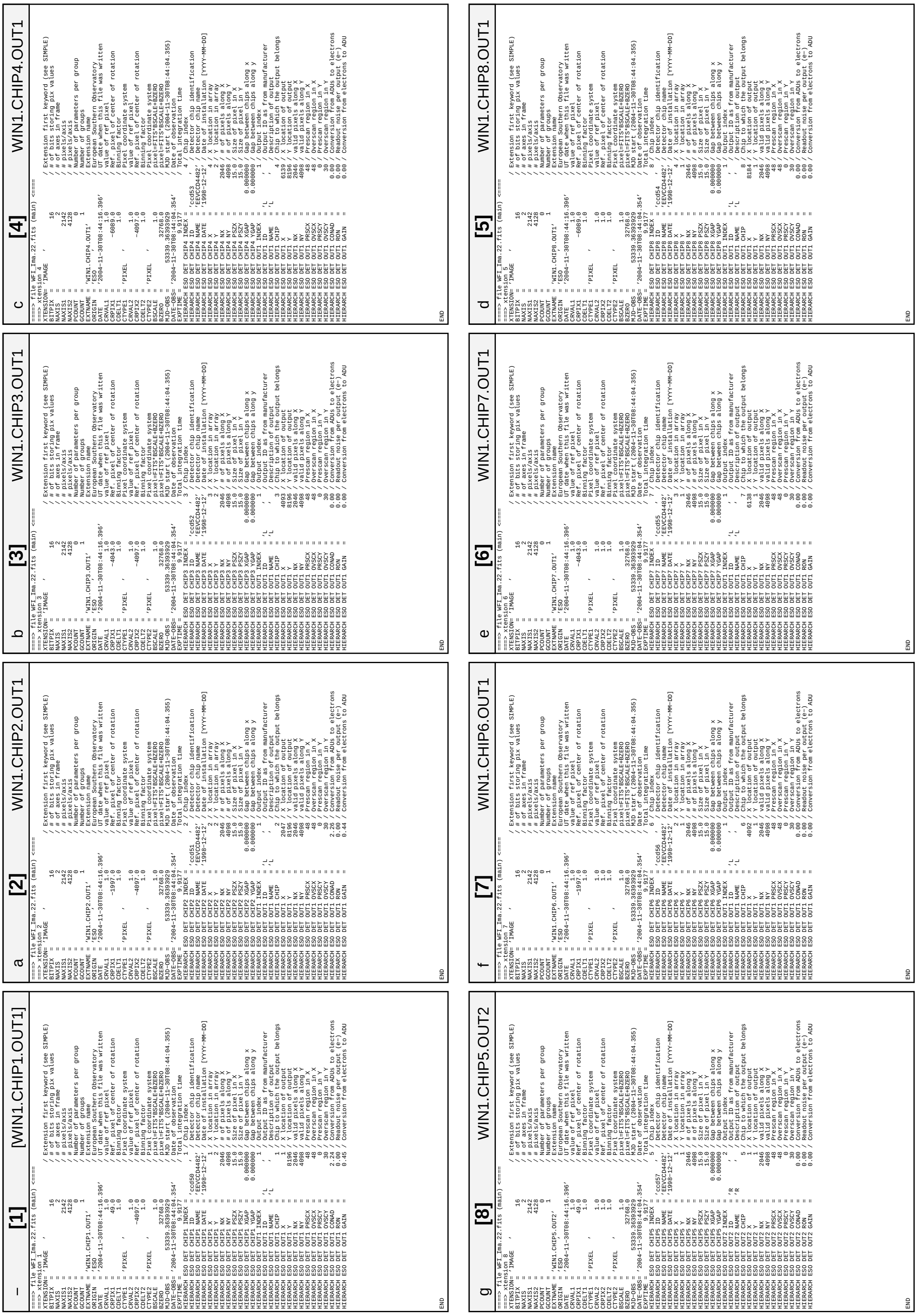

Figure 2.14: WFI extension headers ordered according to the CCD arrangement on the focal plane.

2.3 Instrument layout

2.3.1 Optical components in the light path

The optical path of WFI includes two aluminum reflections, six lenses in two blocks, i.e. two triplets (Fig. 2.17), the selected filter between the triplets, and the dewar entrance window. This provides an FOV with a diameter of nearly 0.8°. Over this FOV and the wavelength range from 350 to 1000 nm, 80% of the energy is encircles within less than 15 μm, i.e. the CCD pixel size; the only exception is the combination of wavelengths above $\sim$900 nm and of-axis distances in excess of $\sim$0.35°. The throughput is near 80% from 400 to 1000 nm but drops steeply to 45% at 350 nm.

Table 2.4 shows the transmission as a function of wavelength for the WFI double-triplet camera.

Table 2.4: WFI dual-triplet system transmission.

Wavelength	350 nm	365 nm	400 nm	600 nm	800 nm	1000 nm
Transmission	0.468	0.716	0.811	0.824	0.801	0.781

2.3.2 The WFI filters

The filter wheel has 50 positions. The filters come in two varieties, most being 6"×6" square filters, and three circular ones with a diameter of 210 mm (Rc ESO 844, Ic/lwp ESO 845, and the "White"). Changing filters takes approximately 65 seconds: 45s + 2.5s×(difference in position number of the filters). The filters currently available are listed in Table 2.5. The transmission data and characteristics were measured by the optician at La Silla (http://filters.ls.eso.org).

The filters which define the standard system are the BB#U50_ESO877, BB#B/123_ESO878, BB#V/89_ESO843, BB#Rc/162_ESO844, and BB#I/203_ESO879, and these are the only ones in the Standard Calibration Plan. Although some effort was spent in trying to match the standard passbands, the U filter, and specially the B filter do a poor job at it. In some applications it might be necessary to work on the WFI system itself, as it becomes impossible to transform to the standard system (i.e. observations of highly reddened stars with the B filter).

The numerous medium and narrow-band filters have been chosen such as to permit photometric redshifts to be determined of distant emission line galaxies and quasars. The choice is based on the existence of three atmospheric windows that are relatively free of night-sky emission lines: 694-706 nm (A), 814-826 nm (B), and 910-926 nm (C). If a strong emission line falls into one of them and another emission line is detected in a second narrow-band filter, the spacing between the filter passbands fixes the redshift if the spacing is chosen such that only one combination of redshift and wavelength difference between major emission lines can lead to such a double coincidence [19]. Table 2.6 shows the redshifts at which the given lines (H_α, [OII], [OIII], or [SII]) would fall into one of the night sky windows A, B, or C.

Figure 2.18 shows the WFI response functions for the broad-band, medium-band, and narrow-band filters plotted against the night sky spectrum (Patat 2003), clearly showing

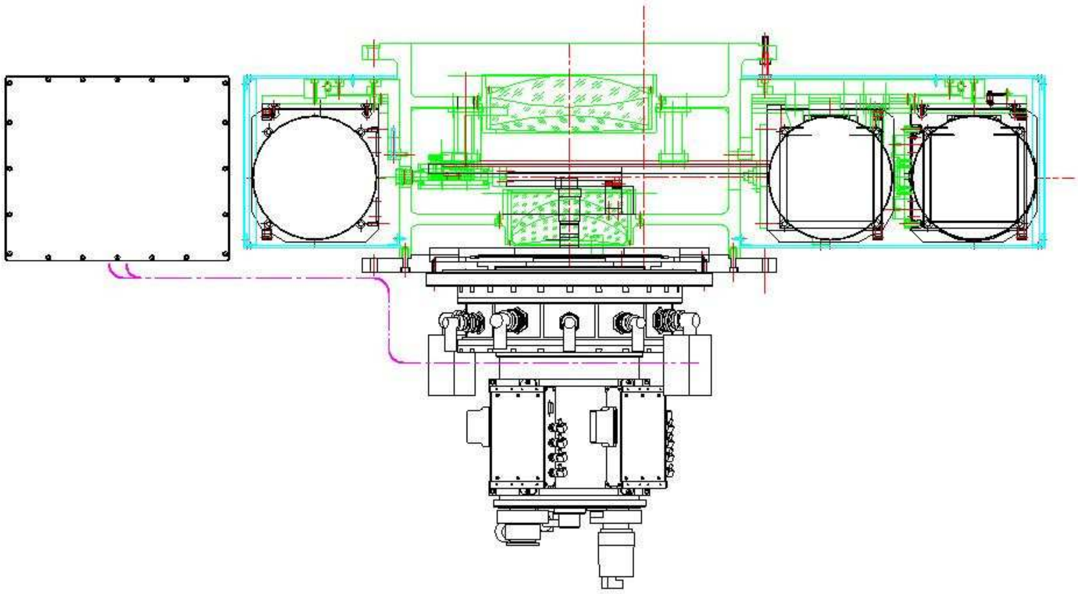

Figure 2.15: The main components of the WFI: The outer circles are cross sections of the filter storage ring (cf. Fig. 2.16). The lenses of the focal reducer are hatched (cf. Fig. 2.17). The ring below is the flange which attaches the dewar to the instrument. The short cylinder with the vacuum connectors, through which the CCD's communicate with the outside world, is the cryostat head and contains the detectors. The liquid nitrogen needed for cooling the detectors is contained in the tank below to which the pre-amplifier boxes are attached. The large rectangle on the left is the box with the FIERA detector control electronics (Sect. 2.2.1). It also serves to counterbalance the torque exerted on the telescope by the off-centre position (with respect to the optical and mechanical axis of the telescope) of the filter storage ring (see also Fig. 2.16). Most cables, the hoses for the water cooling of FIERA, an emergency vacuum pump for the dewar, and several minor components are not shown. Also omitted are the protective shutter above the top lens and the support system for grisms which can be mounted in front of the first lens

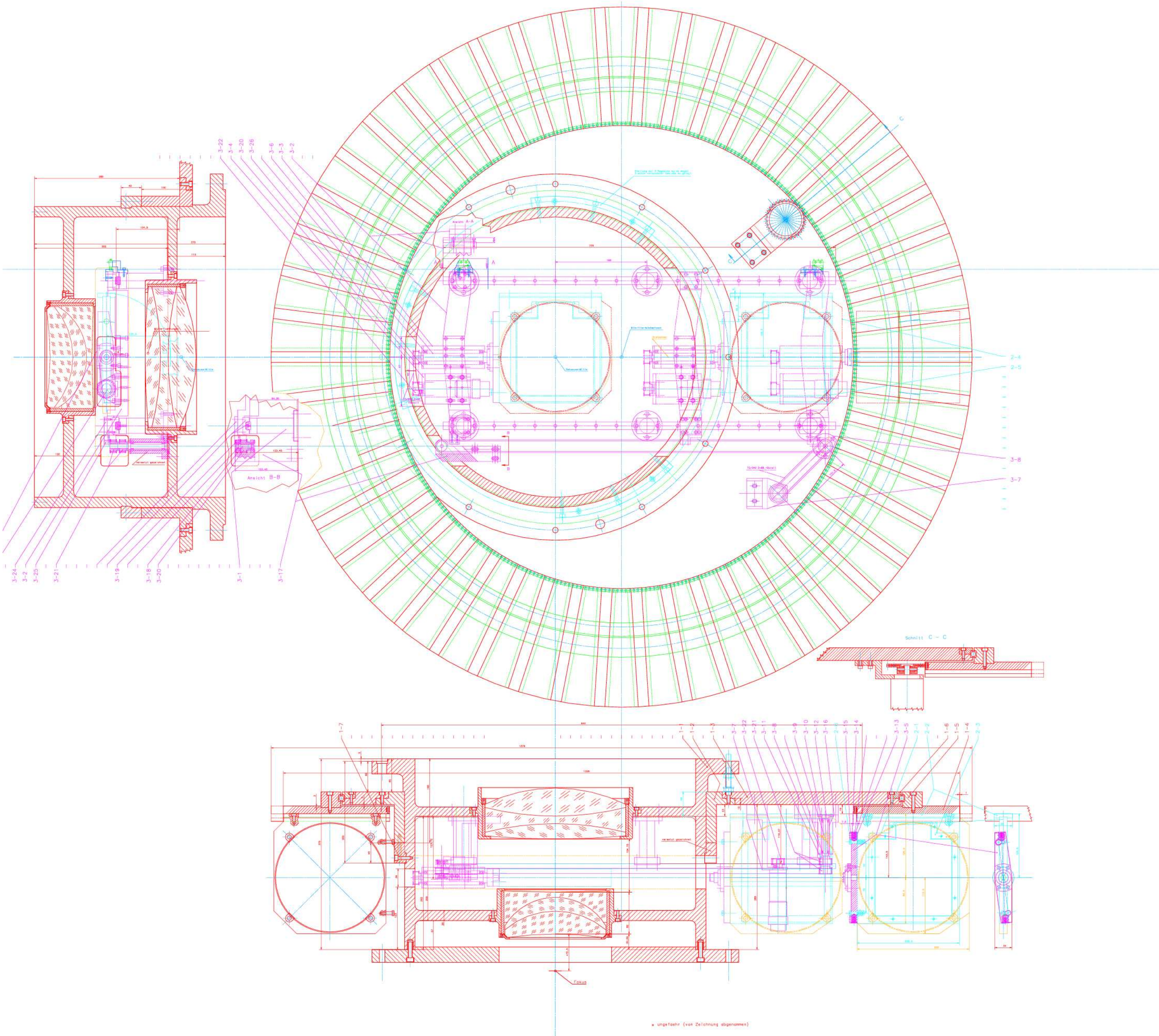

Figure 2.16: The filter exchange and storage mechanism as seen from the top of the instrument, together with two orthogonal vertical crossections of WFI. The large (rotatable) outer ring contains slots for 50 filters which are stored vertically. On the right-hand side a filter, when requested, is pulled out of the ring, rotated through 90°into the plane of the drawing (this position is shown), and finally shifted to the left into the optical beam and operating position (this position is also shown). Note that the filter storage ring is not centered on the optical axis of the telescope and instrument. The resulting net torque requires that the telescope balancing is checked when the instrument is rotated out of the default position angle.

Table 2.5: The WFI filter set

Filter No.	Cal Plan	Filter name	λ_c [nm]	FWHM [nm]	λ_p [nm]	T_p [%]	IQ	Leak [e.u.]	F.O.	Pos	Form	Comment
Broad band filters												
877	•	U/50	340.4	73.2	350.3	82	care	y	-100	12	S	Broadhurst filter
878	•	B/123	451.1	133.5	502.5	89	—-	y	-80	14	S	new B filter
842		B/99	456.3	99.0	475.0	91	accept	y	0	11	S	interfer.; high effic., avoids 400 nm
…		Washington_M	511.2	108.9	508.0	85	…	n	…	36	S	No ESO number
843	•	V/89	539.6	89.4	523.0	87	accept	n	-100	13	S	BG39/2 + GG495/2; approx. V_J
844	•	Rc/162	651.7	162.2	668.5	94	good	y	-50	15	C	OG 570/3 + Calflex; approx. R_C
879	•	I/203	826.9	203.0	760.0	87	—-	-	-127	16	S	New EIS broad band I filter
845		Ic/lwp*	783.8	lwp	1001.0	98	good	n	-55	17	C	RG 780 + CCD; approx. I_C
846		Z+/70	964.8	61.6	956.1	95	accept	y	-20	18	S	LPF 925 + CCD; formerly Z+/60[3]
Medium band filters												
841		U/38	363.7	38.3	362.5	52	accept	n	-75	6	S	interf.; simil. to Strømgren u
872		416/29	416.7	29.9	421.0	76	accept	n	-5	38	S	
873		445/18	445.5	18.2	451.5	83	good	n	-40	32	S	
874		461/13	461.5	13.8	464.5	83	accept	n	-11	24	S	[OII], z= 0.23…0.27 (B)
860		485/31	485.8	31.5	485.0	89	care	n	-40	7	S	
871		516/16	516.5	16.2	519.5	90	care	n	-50	49	S	
862		518/16	518.8	16.3	519.5	89	care	n	-35	8	S	[OII], z= 0.37…0.42 (C)
875		531/17	531.5	17.7	531.0	87	care	n	0	9	S	
…		513/15	510.4	15.9	510.0	86	accept	n	0	37	S	No ESO number
…		549/16	545.5	13.4	545.5	77	care	n	…	10	S	No ESO number
863		571/25	571.3	25.5	571.5	89	care	n	-45	27	S	
864		604/21	604.3	21.0	605.0	94	accept	n	-30	33	S	[OII], z = 0.59…0.65 (B)
866		620/17	620.9	19.4	624.5	95	care	n	-5	39	S	[OIII], z = 0.23…0.26 (B)
867		646/27	646.3	27.7	637.5	91	accept	n	-10	30	S	
868		679/19	679.3	19.7	681.0	91	care	n	-30	41	S	
869		696/20	696.3	20.7	695.5	93	care	n	-20	26	S	[OII], z = 0.82…0.88 (C)
847		721/25	721.8	25.6	721.5	89	care	n	-40	40	S	
848		753/18	753.2	18.3	751.5	94	accept	y	-25	29	S	M-star peak
849		770/19	770.5	19.4	771.0	96	accept	y	-25	22	S	M-star trough, NS window
850		790/25	790.6	25.9	791.0	68	care	y	-20	42	S	
851		815/20	815.9	20.9	821.4	83	accept	n	-20	23	S	NS window: H_α, z = 0.23…0.26, and [OIII], z = 0.60…0.65; Formerly 815/27 (see note 3)
852		837/20	837.8	20.1	842.7	87	good	y	-10	43	S	Formerly 838/25 (see note 3)
853		856/14	856.2	14.3	857.1	88	good	y	-20	21	S	M-star trough; NS window
870		884/39	884.2	39.7	890.1	95	good	n	-55	44	S	
854		914/27	914.8	27.5	918.3	93	care	y	-25	20	S	NS window: H_α, z = 0.37…0.42, and [OIII], z = 0.79…0.85; Formerly 915/28 (see note 3)

Table 2.5: (cont.) The WFI filter set

Narrow band filters												
865		396/12	396.3	12.9	399.0	66	accept	n	-50	31	S	[OII], z = 0.04…0.10 (A)
859		OIII/8	502.4	8.0	502.0	88	accept	y	-15	4	S	$z \sim 0$
···		OIII/2	502.6	2.8	502.6	80	good	n	-30	28	S	See note 2.
···		Gieren 501	500.7	2.7	500.7	79	good	n	0	35	S	Property of W. Gieren
861		504/10	504.7	10.3	504.0	89	accept	n	-40	34	S	[OIII], z = 0…0.02; formerly 506m
856		H_α/7	658.8	7.4	658.5	91	accept	y	-10	19	S	$z \sim 0$
858		665/12	665.6	12.1	667.5	86	accept	y	-25	25	S	
857		SIIr/8	676.3	8.4	675.8	84	accept	n	-30	3	S	[SII], $z \geq 0$; see note 4
···		810/6	809.2	22.1	809.0	28	bad	n	-100	2	S	MPIA/Meisenheimer
···		824/7	···	···	···	···	care	n	-100	5	S	MPIA/Jones et al.
···		817/7	···	···	817.6	87	care	n	-100	45	S	MPIA/Meisenheimer

Notes:

1 The reported λ_c is the short wavelength edge.

2 Property of the Observatory of Capodimonte. Availability and quality not guaranteed. Note that this filter is 144x144mm.

3 Due to a setup error of the spectrophotometer, an error was made in the measurement of the filter's λ_c and FWHM. These filters were remeasured, and this database was updated to reflect these changes (and subsequently new names) on 16 December 1999. The former filter name is indicated on the table (note that 884/39 did not undergo a name change).

4 Prior to 8 February 2000 this filter was mistakenly identified as SIIr/5.

5 Prior to March 2000 this filter had an incorrect Tx curve plotted on the web.

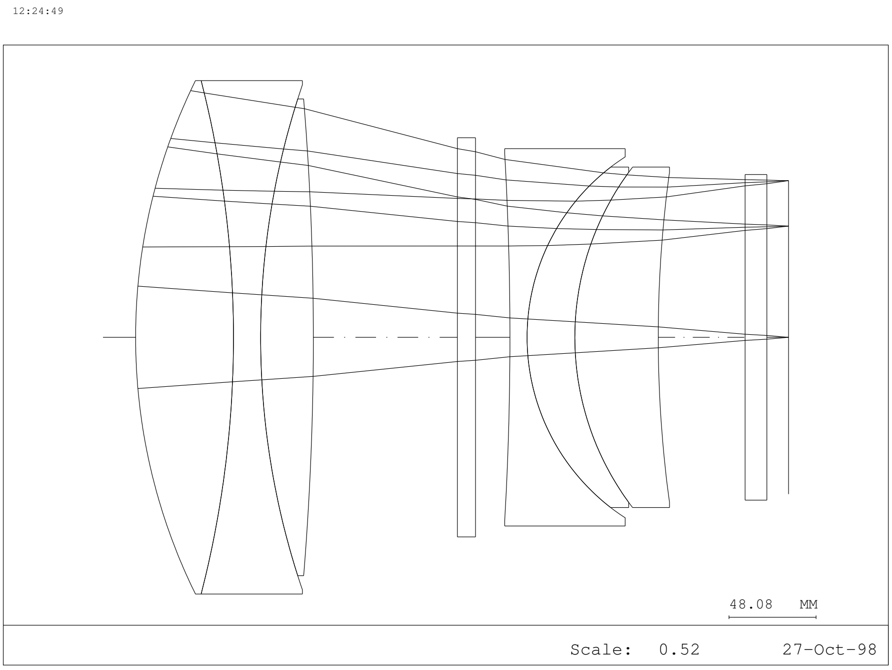

Figure 2.17: The optical layout of the focal reducer. From left to right are shown the first triplet, a filter, the second triplet, the dewar entrance window, and the focal (detector) plane.

Table 2.6: Redshifts for atmospheric window-spectral line coincidence

Line	Window A 694-706 nm	Window B 814-826 nm	Window C 910-926 nm
Hα	0.070±.0005	0.249±0.006	0.402±0.007
[O III] λ5007	0.402±0.007	0.638±0.008	0.837±0.009
[O II] λ3727	0.884±0.009	1.200±0.011	1.468±0.012
Ly-α	4.77±0.03	5.75±0.03	6.57±0.04

the A, B, and C windows. The response functions include two mirror reflections, the WFI throughput, the filter transmissions, and the CCD response. The upper envelope in the broad band filter plot corresponds to the no filter throughput, while the slightly lower envelope, specially in the blue, includes the "White" filter, a large, round, transparent glass. Notice that we have included the Washington M filter in the broadband category, and the U/38 in the medium band category, a departure from our previous usage. The large departure from the standard passband of the B filter should be specially worrisome (see below).

2.3.2.1 User-supplied filters

Due to the special characteristics of the WFI filters we do not normally mount special filters. If you want to do so you must get the agreement from ESO's USD (usd-help@eso.org) during Phase I, and then provide the filters to La Silla at least 2 months prior to the observations. The following constraints need to be met but are not guaranteed to be sufficient:

- The *optical* thickness must not deviate by more than 1mm from the one of the nominal filter used for the optical design (11mm BK7).
- In case of very broad-band filters, the Abbe number of the substrate must be larger than 55.
- Size: (a) 6"×6" plus broad-band auxiliary filter, or (b) 210 mm diameter.
- Holder: Only holders made by the Max-Planck-Institut fur Astronomie in Heidelberg are admissible. For details contact La Silla SciOps.

2.3.3 Image quality

The best seeing that one may expect to measure in images taken with WFI on the MPG/ESO 2.2-m telescope is about 0.5″, with the I filter, and under conditions of extreme good site seeing, and **favorable viewing conditions:** the airmass below 1.2 to reduce the effect of differential atmospheric refraction; the target should be toward the north so that the dome slit points in the direction of the prevailing wind, and the wind should be above ∼3 m/s and below ∼12 m/s, to insure proper mirror ventilation; the mirror should be at a lower temperature than the ambient air. Such conditions seldomly occur, and when they do they last only few minutes (15?). A reasonable best seeing limit in the V filter is 0.7″, and more generally good seeing is 0.9″. The typical seeing in V is 1.1″, and usually 0.2-0.4″ worse than the DIMM values.

Figure2.19 show the comparison of seeing measured on the images taken with WFI and the simultaneous DIMM seeing.

2.3.3.1 Differential atmospheric refraction

Although[3] not part of the instrument per se, the atmosphere is another "optical element" in the light path that affects the image quality. A ray of light incident in the upper atmosphere

[3]These important sections were added after the editor read the not yet released *OmegaCam Users Manual* by K. Kuijken.

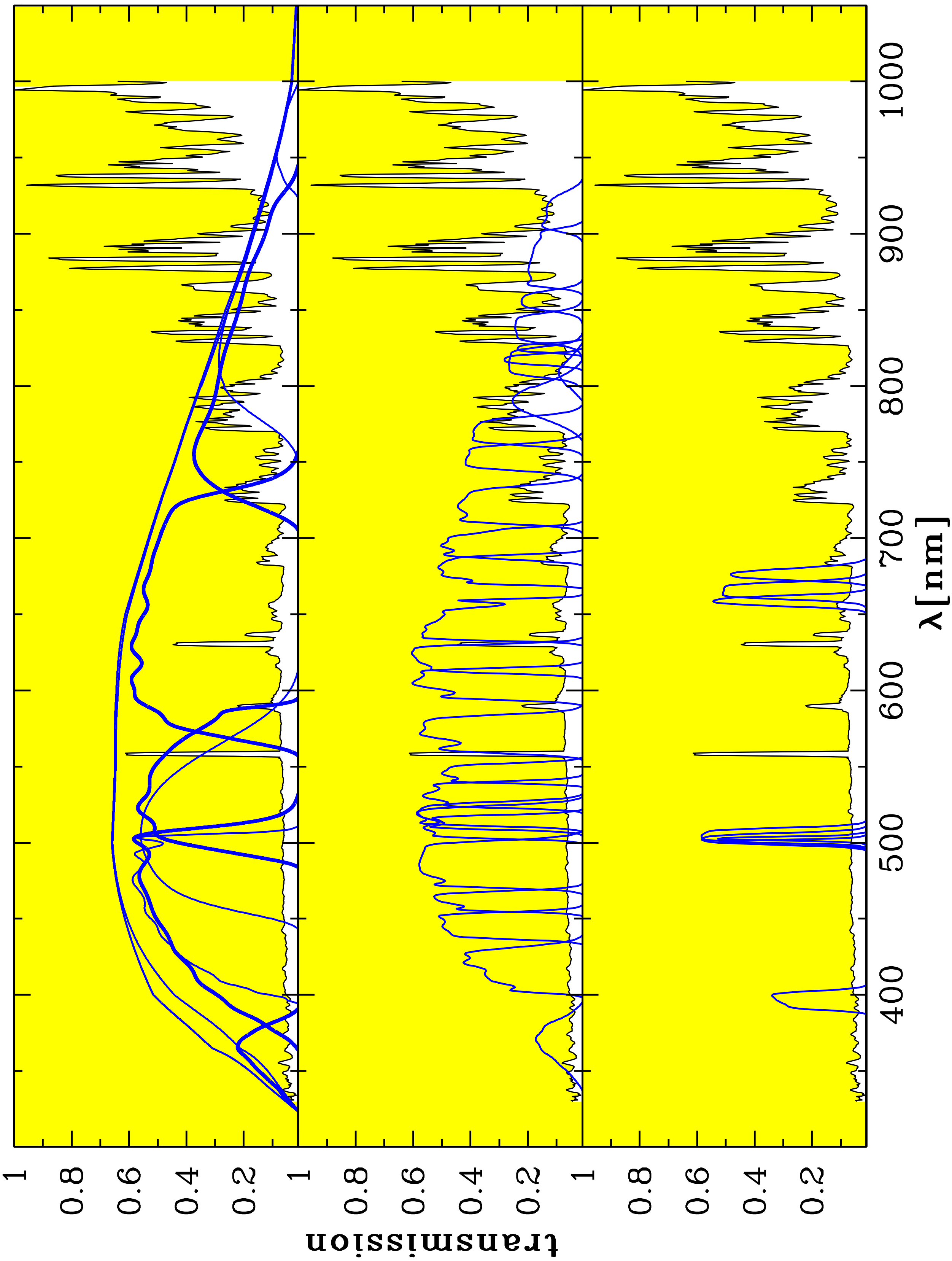

Figure 2.18: WFI filters plotted over the sky spectrum from Patat (2003).

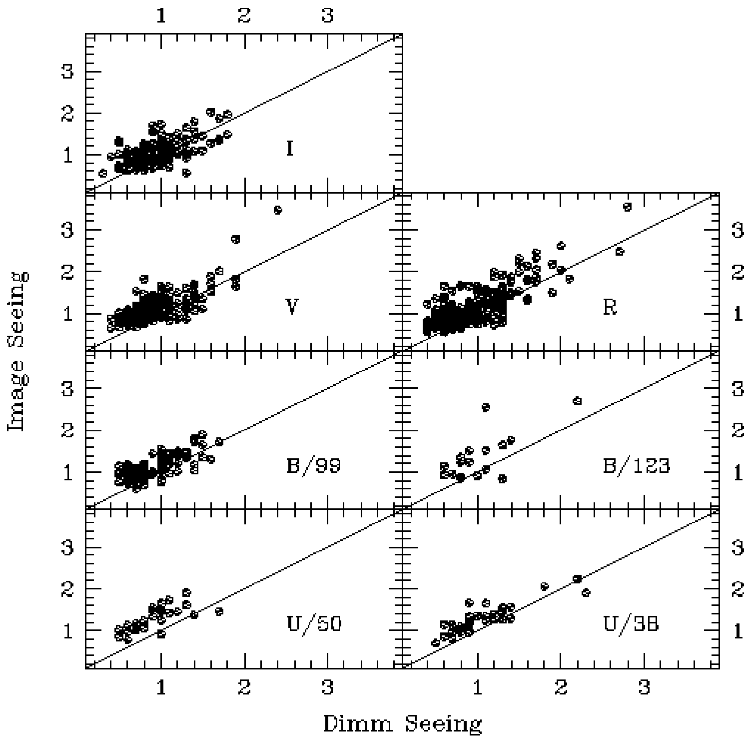

Figure 2.19: WFI image quality versus DIMM seeing. The straight lines are the one-to-one lines.

with a zenith angle θ, will be refracted downward and will reach the earth surface with a zenith angle $\theta - R$, where the angle R is given approximately by

$$R \approx (n-1)\tan z \approx 58''\!.2 \tan z$$

where z is the zenith angle at the earth surface, and n is the index of refraction near the earth surface. R varies over the field of WFI leading to a deformation of the image with respect to what would be observed in the absence of the atmosphere. The differential change from center to edge is given by

$$\delta R \approx (n-1)\sec^2 z \delta z,$$

which for δz ~$0^\circ\!.25$ results in a shift of $0''\!.25 \sec^2 z$. This effect finally results in an expansion of the image in the direction of the parallactic angle by a factor $2\delta R \sim 0''\!.5 \sec^2 z$.

If the integration time is long enough the stellar images near the edges will appear smeared. To estimate the length of an exposure for the smearing to be less than $0''\!.1$ we can use the formula

$$\delta z < 11^\circ\!.5 \cot z \cos^2 z,$$

which for $z = 45^\circ$ corresponds to $\delta z < 5^\circ\!.75$, and for $z = 60^\circ$ corresponds to $\delta z < 1^\circ\!.7$. For a field at the celestial equator observed from La Silla this corresponds approximately to integration times of 26 and 7 minutes respectively. Notice that the image degradation can be quite considerable for long integration times, as the dependence on z is non linear.

Table 2.7: Atmospheric dispersion for WFI filters, in arcsec FWHM.

Airmass	U/50	B/123	V/89	Rc	I/203	Z
1.00	0.00	0.00	0.00	0.00	0.00	0.00
1.05	0.36	0.15	0.10	0.10	0.06	0.01
1.10	0.50	0.21	0.14	0.14	0.08	0.02
1.15	0.62	0.26	0.17	0.17	0.10	0.02
1.20	0.74	0.30	0.20	0.20	0.12	0.03
1.30	0.92	0.38	0.25	0.26	0.15	0.02
1.40	1.09	0.44	0.29	0.30	0.18	0.04
1.50	1.23	0.51	0.34	0.34	0.21	0.03
1.60	1.37	0.56	0.38	0.39	0.24	0.04
1.70	1.52	0.62	0.41	0.43	0.26	0.05
1.80	1.65	0.68	0.46	0.46	0.28	0.05
2.00	1.91	0.78	0.52	0.53	0.38	0.06
2.50	2.53	1.04	0.69	0.71	0.42	0.08
3.00	3.12	1.28	0.86	0.88	0.52	0.10

2.3.3.2 Atmospheric dispersion

Another effect that needs to be considered when using broad band filters is the fact that light of different colours suffers a different amount of atmospheric refraction. By acting as a prism the atmosphere disperses the light along the direction of the parallactic angle turning the stellar images into little spectrae.

Table 2.7 shows the dispersion, in arcsec, for the standard WFI filters. The table displays the length of the stellar image along the direction of the parallactic angle. It was calculated using the FWHM of the WFI filters using an adaptation of the IDL program by E. Marchetti to be found at
`http://www.eso.org/gen-fac/pubs/astclim/lasilla/diff_atm_refr.pro`
Notice how rapidly the image quality deteriorates with airmass in the U filter.

2.4 Known imperfections and deficiencies

Nothing is perfect and so is the Wide Field Imager. Depending on their requirements, users may wish to carefully consider the following points (a more extensive and continually updated list is maintained in the form of *A Practical Guideline for WFI Observers* which can be copied from the WFI WWW home page mentioned in Sect. 1.3):

Bias variation: After each (re-)start of an observing session, the bias values can differ from the previous ones by a few ADU's. When the CCD's have been idling for some time, it is recommended to take a few bias exposures before taking any calibration or science exposures so that the system can reach equilibrium. Thereafter, bias values should remain constant. Chip-to-chip differences in bias value are normal as the offsets can be fine-tuned only imperfectly.

Bias from overscan pixels: Because of this variability, it is often best to use the bias values in the overscan pixels. Because of the finite response time of the control electronics, the bias level depends on the signal level in the corresponding light-sensitive part of the row: if there is a bright star in the row one can sense this from the horizontal overscan pixels. This can ialso be seen in flat field exposures where the bias value increases over a few hundred rows asymptotically from the row closest to the readout port.

Stray light from the tracker: In spite of shielding, light of a bright star falling onto the tracker CCD can be reflected onto the science mosaic. A similar effect is seen in flat field exposures through filters with an auxiliary filter for the tracker. Because the bandwidth of the auxiliary filter is usually larger (in the case of medium- and especially narrow-band filter: very much larger) than the one of the main filter, the excess light partly scatters onto the mosaic. This is visible as a band of enhanced brightness along the height of the tracker CCD.

Vignetting by filter holders: On some interference filters the optically active coating does not quite extend over the full size of the filter. In order to avoid contaminating unfiltered light, the edges of such filters have been masked off by the filter holder. This appears as a slight vignetting over the outermost couple of hundred pixels.

Light scattering by filter holders or dewar entrance window: When a bright star is positioned just outside the field of view it creates a strong light "fountain" of scattered light. The light pours in at a right angle with respect to the edge of the field. It is visible when the star is within the first 90″outside the directly observable field. With about 300″length, the beam of scattered light reaches it largest extent when the star is about 60″outside the field. If such a situation arises, the best remedy is to place the disturbing star at least 100″outside the FOV. Putting it within the FOV can still be the next best solution.

Optical ghosts: Very bright sources lead to the appearance of two images of the pupil on the diagonally opposite side of, and at about the same and twice the distance from, the center of the FOV. For a direct image saturating the A/D converter a few hundred times, the first ghost reaches a level of a few tens of ADU per pixel; the second one half that much. The first one measures about 100″, the second one 200″in diameter.

Heavy saturation: Without binning, the amplifier can no longer cope with the charges once about 40-fold saturation of the A/D converter is reached, and the pixels concerned suddenly turn 'black'. This point is reached very much earlier with 2×2 and especially 3×3 binning.

Delayed closure of shutter: In very few cases it has been noticed that the shutter closed only after readout of the CCD had started. The give-away symptom is that the images of all sources, faint or bright, have slightly wiggly tails towards the central East-West symmetry axis of the mosaic. This is not be confused with charge overflow which only occurs with strongly overexposed pixels and always follows a perfectly straight line (namely CCD rows). From the very small numbers of cases observed, it seems that this problem occurs preferentially with exposure times below 2 seconds.

Dewar temperature and cosmetic defects: Laboratory tests with the WFI CCD's in a single-chip dewar have shown that at temperatures 10°-15°below the WFI operating temperature of 167 K, more cosmetic defects freeze out at almost no loss in sensitivity. At least as important is that the operating temperature is stable. This is the case. But although all possible efforts were made, the large size of the dewar entrance window and the thermal leakage associated with it did not permit a safe, lower operating temperature to be set. *It has become necessary during some summers to raise the temperature to 169 K.*

Astigmatism: At the time of writing, the telescope suffers significant astigmatism outside the circum-zenithal region, especially at positive hour angles. This leads to an elongation of stellar images by typically 0.5 to 1 pixels. When the difference between the current position of the telescope and the one, where the last focus sequence was made, exceeds $\sim 30°$, a new focus sequence is advisable.

Filter exchange mechanism malfunction: Especially at large zenith distances it can happen that the filter exchange mechanism really fails or only erroneously detects a malfunction. The recipe to correct this problem is known to the telescope operators.

Differential guiding: As of this writing (2005-02-30), the differential guiding system of WFI is not offered.

FIERA troubles: The WFI FIERA system suffers a few problems that are expected to be solved when we change to a new version of the embedded computer at the end of March 2005. This should result in a considerable reduction of system down time.

Telescope focusing troubles during the summer: There is a problem with the telescope focusing that occur only during the summer months which causes that sometimes the focus never reaches the requested value.

Chapter 3

Photometric properties of WFI

Table 3.1 show the colour equations of WFI in the standard bands UBVRI, henceforth *key-bands*. The equations assume that the data is measured in ADU. We can predict the expected number of ADUs by using those equations as follow: for the V/89 filter we can write

$$V/89 = V - 24.15 + 0.13 \times (B - V),$$

thus, for a $V = 12$, A0 V star, with $(B - V) = 0.0$ we expect $\mathrm{V}/89 = -12.15$, or 7.24×10^4 ADU/s $\sim 1.45 \times 10^5\, e^-$/s, for a nominal gain of 2.0. This is reduced by a factor of 0.90 for an airmass of 1.0, to $1.31 \times 10^5\, e^-$/s.

3.1 The exposure time calculator

ESO maintains an exposure time calculator (ETC) for WFI, which can be used to estimate exposure times, S/N, etc for observations with WFI in the keybands, and a few other selected filters. At the time of this writing the filters in the ETC for WFI are: U/50, U/38, B/123, V/89, Rc, I/203, and Z+. The exposure time calculator for WFI can be found at the URL

`http://www.eso.org/observing/etc/`

The application of the WFI ETC for the example we calculated above yields $1.28 \times 10^5\, e^-$/s, well within the 20% accuracy expected from the ETC.

Table 3.2 can be used for all filters available other than those in the ETC. The table was calculated by simulating two aluminum reflections, the WFI triplet throughput, the filter

Table 3.1: WFI colour equations

Equation	Atmospheric extinction
U-U/50 = 22.06 + 0.05(U-B)	0.48
B-B/123 = 24.81 + 0.25(U-B)	0.22
V-V/89 = 24.15 -0.13 (B-V)	0.11
R-Rc = 24.47 + 0.00 (V-R)	0.07
I-I/203 = 23.37 + 0.03 (V-I)	0.10

Numbers in colour equations are in log(ADU). To change to electron we would need to add 0.75 to the zero points.

transmission curve, and the CCD quantum efficiency. This table lists the factors by which we need to multiply an exposure time in the V filter, to obtain a similar S/N in any other filter. These factors depend on the spectrum of the source in question, and the table was calculated using Kurucz model atmospheres for a full range of stellar spectral types, assuming and airmass of one. The table also lists the factor for a flat-spectrum source observed at airmasses of 1.0 and 2.0.

3.2 Special challenges for WFI photometry

Several characteristics of WFI complicate the reduction of photometric data. First, the detector non-linearities can be larger than $\pm 1\%$ between a few ADUs and 50,000 ADU. Second, the differences in the band-passes compared with the standard band-passes introduces uncertainties which can be as large or larger than 10%. Finally, the variation of zero points across the mosaic (yes, after flat fielding) has been reported to induce a position dependent variation of up to 20 % peak-to-valley. To reduce systematic errors below 10% it is imperative that these effects be taken into consideration.

3.2.1 Band-pass mismatch errors

The bottom panel of Figure 3.1 shows the (normalized) WFI and Johnson band-passes together with the model spectra for a 40000 K star ($\log g = 4.5$), for a 10000K dwarf ($\log g = 4.5$), and for a 10000K giant ($\log g = 2$). These spectra show the number of photons as a function of wavelength, N_λ, as this is the one relevant for *photon counting* devices. Here the results of simulating the colour equations are presented. The method used follows closely the work of Buser and Kurucz (1978) using the latest ATLAS9 models from the web (Kurucz 2002) and the latest Vega calibration (Castelli and Kurucz 1994; Kurucz 2002).

Figure 3.2 shows the resulting simulated colour equations. The upper left panel shows the colour-colour diagram for the following three sets of data: (1) the Schmidt-Kaler (1982) locus for dwarfs; (2) the Kurucz model atmosphere colours for dwarfs, giants, and supergiants, somewhat arbitrarily defined as having $\log g$ of 4.0, 2.0, and 0.5, respectively; and (3) the observed colours for the Landolt (1992) stars in the fields Ru149, and TPhe used to determine the observed colour equations. The upper right panel shows the observed colour equation for U together with the simulated colour equations for dwarfs, giants, and supergiants. The lower two panels show the same for B (left) and V (right). Figure 3.2 shows that to within $\sim 1\%$ the simulations of the B and V bands agree with the observations for most stellar types (red objects are notoriously difficult to simulate).

Figure 3.2 shows that the simulated colour equation for the U band has a strong dependence on the luminosity class. Had the WFI system not being simulated it would have been tempting to apply a non-linear functional dependence on the colour term. However, it can be seen from the simulations that *no functional relationship represents the transformation from WFI U to standard Johnson U.* Using a non-linear correction term would introduce a luminosity class dependent error of almost 10% in some cases. The only way to deal with such an effect is to work in the WFI system itself and to transform the theoretical colours to this system.

Table 3.2: Integration times factors relative to V.

Filt. No.	Filt. name	Flat spect. 1.0	Flat spect. 2.0	O3	B0	A0	F0	G0	K0	M0
877	U/50	7.55	11.54	2.65	3.09	11.74	13.21	18.40	32.08	108.06
841	U/38	10.78	15.82	4.02	4.63	14.80	17.59	24.81	42.97	117.19
878	B/123	0.80	0.96	0.50	0.52	0.63	0.78	0.93	1.07	1.60
842	B/99	0.95	1.12	0.61	0.63	0.73	0.90	1.06	1.20	1.76
···	Wash_M	0.78	0.88	0.69	0.69	0.72	0.77	0.79	0.81	0.91
843	V/89	1.00	1.11	1.00	1.00	1.00	1.00	1.00	1.00	1.00
844	Rc/162	0.49	0.52	0.83	0.82	0.72	0.58	0.50	0.44	0.30
879	I/203	0.80	0.81	2.51	2.42	1.82	1.24	0.94	0.77	0.33
845	Ic/lwp	0.98	0.99	3.77	3.60	2.54	1.68	1.24	0.98	0.37
846	Z+/70	9.33	9.42	48.84	46.07	27.75	18.53	13.20	9.97	3.14
White	White	0.16	0.17	0.18	0.19	0.20	0.19	0.18	0.17	0.11
872	416/29	4.58	5.76	2.31	2.41	3.08	4.44	6.25	8.60	17.21
873	445/18	5.33	6.38	3.20	3.30	3.81	4.94	6.12	7.23	10.34
874	461/13	6.79	7.93	4.51	4.61	5.07	6.18	7.08	7.72	10.24
860	485/31	2.61	2.98	1.99	2.03	2.27	2.52	2.68	2.81	3.98
871	516/16	4.89	5.47	4.42	4.43	4.55	4.81	5.09	5.50	8.00
862	518/16	4.74	5.30	4.34	4.35	4.46	4.69	4.95	5.32	7.16
875	531/17	4.72	5.23	4.62	4.61	4.64	4.70	4.74	4.76	4.51
···	513/15	5.22	5.85	4.56	4.58	4.74	5.06	5.37	5.80	9.82
···	549/16	6.83	7.56	7.22	7.18	7.05	6.87	6.74	6.61	6.33
863	571/25	3.22	3.54	3.88	3.85	3.63	3.32	3.11	2.92	2.26
864	604/21	3.71	4.02	5.22	5.17	4.70	4.02	3.60	3.27	2.22
866	620/17	3.81	4.10	5.78	5.71	5.10	4.27	3.78	3.42	2.41
867	646/27	3.10	3.29	5.27	5.20	4.65	3.71	3.15	2.77	1.77
868	679/19	4.42	4.59	8.68	8.52	7.13	5.44	4.53	3.91	2.91
869	696/20	4.29	4.45	9.01	8.82	7.27	5.44	4.46	3.82	2.27
847	721/25	3.71	3.82	8.64	8.45	6.80	4.95	4.00	3.39	2.25
848	743/18	5.26	5.37	13.86	13.48	10.57	7.42	5.83	4.83	2.10
849	770/19	5.28	5.38	14.84	14.42	11.16	7.71	5.98	4.90	2.46
850	790/25	5.91	6.03	17.89	17.36	13.22	8.95	6.84	5.57	2.67
851	815/20	7.02	7.15	23.64	22.59	16.78	11.12	8.39	6.79	2.63
852	837/20	7.57	7.65	27.99	26.37	19.53	12.56	9.32	7.47	2.92
853	856/14	11.71	11.82	44.60	43.33	32.04	20.39	14.86	11.72	4.81
870	884/39	5.51	5.56	23.03	22.16	15.02	9.96	7.20	5.61	1.94
854	914/27	10.53	10.63	48.36	46.02	29.38	19.79	14.21	10.88	3.54
865	396/12	12.74	16.91	5.67	5.98	9.07	15.15	23.57	34.47	71.86
859	OIII/8	9.46	10.65	7.90	7.99	8.34	9.15	9.79	10.40	17.14
···	OIII/2	26.33	29.60	22.23	22.47	23.44	25.60	27.39	29.03	45.71
···	Gieren_501	28.41	32.00	23.59	23.98	25.04	27.90	30.20	32.19	51.79
861	504/10	7.37	8.29	6.24	6.29	6.55	7.10	7.54	8.01	13.52
856	H_α/7	10.13	10.62	18.54	18.44	17.55	13.38	10.80	9.19	5.52
858	665/12	6.59	6.88	12.21	12.03	10.36	8.03	6.70	5.82	3.77
857	SIIr/8	9.88	10.26	19.13	18.79	15.79	12.09	10.07	8.71	6.75
···	810/6	19.33	19.69	62.84	60.60	45.35	30.21	22.86	18.54	7.57
···	824/7	23.17	23.53	83.19	77.24	56.62	37.38	28.02	22.51	8.38
···	817/7	17.09	17.41	57.78	55.41	41.14	27.21	20.49	16.57	6.35

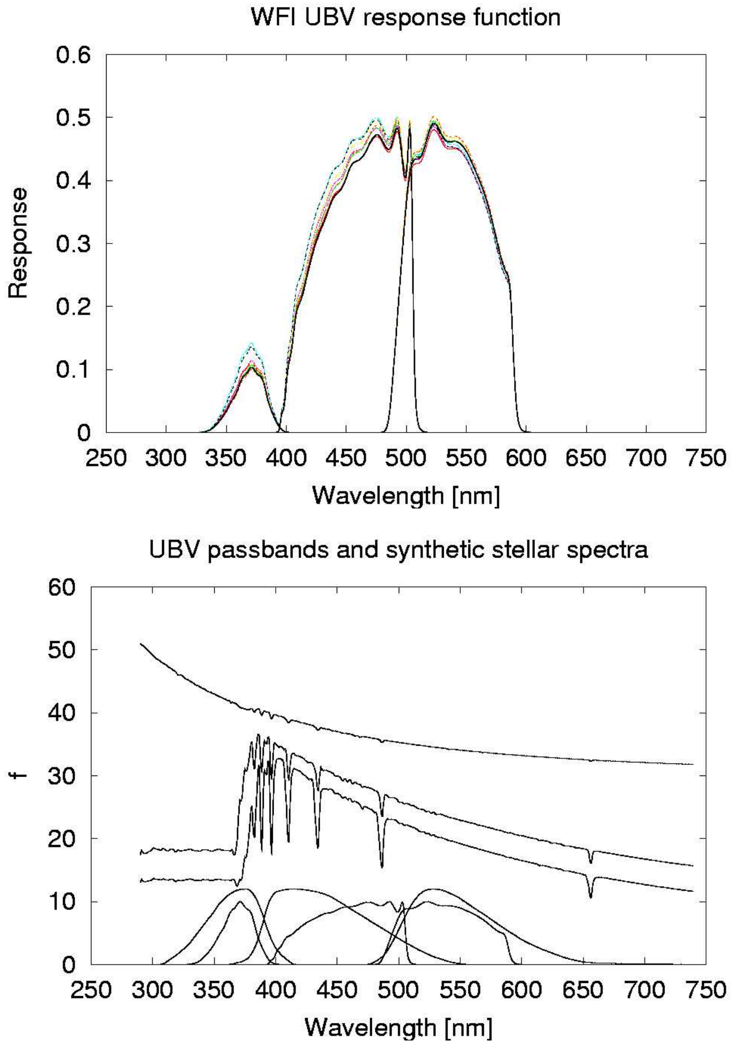

Figure 3.1: The top panel shows the response of the WFI UBV system for the 8 CCD chips. The bottom panel shows the Kurucz (2002) model atmospheres spectra (number of photons as a function of wavelength), together with Johnson and WFI overall response functions (the WFI curves the lower ones). The upper curve corresponds to a $\log g = 4.0$, 40000 K star; the middle curves corresponds to 10000K dwarf ($\log g = 4.0$), and, slightly above, a 10000K giant ($\log g = 2.0$). All these curves have been scaled to fit in the viewport; in particular, the continua shortward of the Balmer jump is almost identical for the the 10000K stars. Notice the large deviations of the WFI system from the standard Johnson system, specially for U and B.

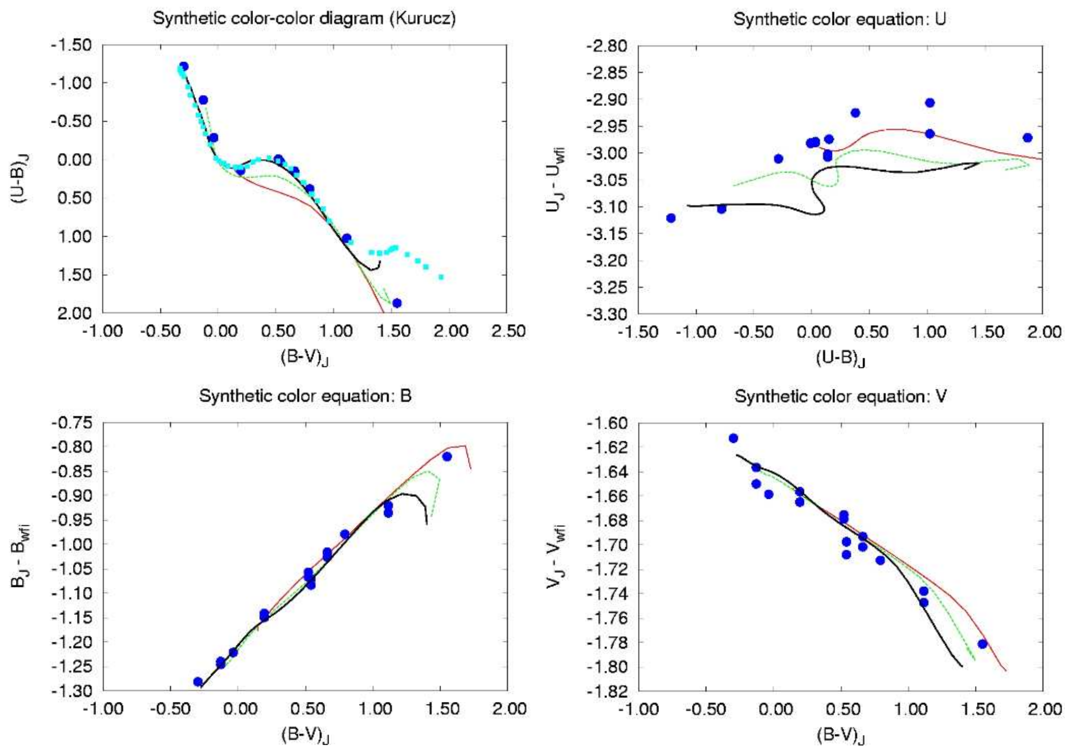

Figure 3.2: The top left panel shows the positions in the colour-colour diagram of the Landolt standard stars (large blue dots) used in the determination of the colour equations. This panel also shows the locus of the dwarfs (small filled green squares) according to Schmidt-Kaler (1982), and the locus of the simulated stars (black line for dwarfs, green line for giants, and red line for super-giants). The upper right panel shows the observed and simulated colour equation for U; lower left and right panels show the observed and simulated colour equations for B and V, respectively.

Figure 3.2 also shows that to within $\sim 1\%$ the simulations of the B and V bands agree with the observations for most stellar types. Nevertheless, most of the Landolt standards have low to moderate reddening values, while a program star can be strongly reddened. Figure 3.3 shows the effect of reddening on the instrumental equations for the U band, upper panel, and for the B band, lower panel (the effect on V is almost negligible). The solid line is the simulated transformation equation for zero reddening while the dashed line corresponds to $E(B-V) = 1.0$. We can see that a reddened extreme O star has a zero point which differs from that of an unreddened star of the same colour by approximately 8% in B and 5% in U, but in the opposite direction. The change in (U-B) is thus a full 13%! Not knowing a priori the reddening of a program stars, it is impossible to transform the magnitudes to the standard system with an acceptable uncertainty.

3.2.2 Photometric zero-point variations induced by light concentration

(This section present the approach used in reference [17]. For other approaches the users should consult other references, such as [13, 12, 3, 2].) Even after applying a flat-field correction the photometric zero points vary with positions in the mosaic [13]. If the flat field screen illumination is uniform, then any observed variations in the flat field image are the result of variations in the transmission of the optics and the response of the pixels. Such a flat

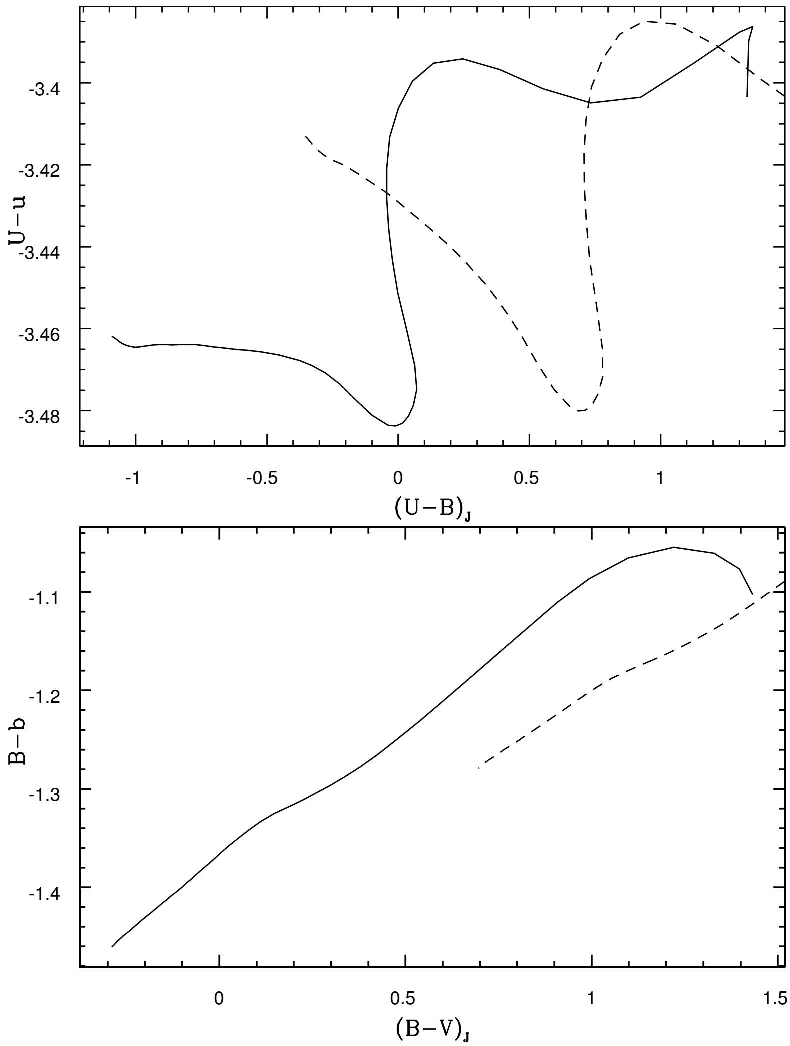

Figure 3.3: Simulated colour equations for the WFI U/38 (u in the figure) and B/99 (b in the figure) band-passes for two different values of interstellar reddening: the solid line corresponds to E(B-V) = 0.0, while the dotted line corresponds to E(B-V) = 1.0. We can see that a reddened extreme O star has a zero point which differs from that of an unreddened star of the same colour by approximately 8% in B and 5% in U. The change in (U-B) is thus a full 13%!

field image can then be used to remove the variations of sensitivity from all science frames.

However, it appears that for large area imagers with focal reducers, even if the illumination of the flat field screen (or twilight sky) is uniform there is redistribution of light by the optical system that corrupts the flat field images. In most cases the non-uniform illumination results in an increase of the amount of light reaching the central areas of the detector (*sky concentration*; [3]). This *sky concentration* mimics a larger central relative response. Thus, when flat fielding with such incorrect flat fields, the fluxes of the stars near the center will be artificially reduced. Notice that a super-flat, produced by median-filtering a large number of offseted frames of the sky will be of no use to improve the accuracy of flat-fielding, because such frames are affected by the same effect.

A flat field image which measures the sensitivity variations, as opposed to the variations in illumination level at the detector plane, is called a *photometric flat*.

Figure 3.4 illustrates the effect of reducing data with a flat field which suffers from sky concentration. The figure shows the colour equations determined using observations of the stars in the Landolt field Rubin 149. Eight exposures were obtained per filter while the telescope was offset between exposures so that the stars, which are very close together, were placed in each of the 8 chips. The images were flattened with flat field frames obtained during twilight. A full atmospheric extinction correction was obtained observing the same field at three different air-masses in the same chip. The magnitudes are then extra-atmospheric and should be independent of the position in the mosaic. The figure shows a large spread in zero-points nearly independent of colour. Thus, the sky concentration effect is manifest as a spatial variation in the zero points of the photometry. A correction frame which equals this spatial variation of the zero points is called a *photometric flat field correction*, or *zero-point variation map.*

The zero-point variation map for the V filter is shown in Figure 3.5, modeled as a ninth-order, 2-D Cartesian Chebishev polynomial (91 coefficients).

Figure 3.6 shows the colour equations determined after applying the zero-point correction map to the V filter. The V filter correction were used also for the U and B filters. Using the V zero-point correction map for all filters the 1σ residuals from the standard stars transformations were reduced from 0.034 to 0.009 in V, from 0.029 to 0.010 in B, and from 0.040 to 0.014 in U; i.e., typically a factor of 3 reduction in the residuals. These are lower limits to the errors as they were determined using the few standard stars in RU149 in only 8 positions across the field. Over the whole field the figure is probably closer to 2%. To reduce these errors further it is necessary to determine the variation map for each filter individually.

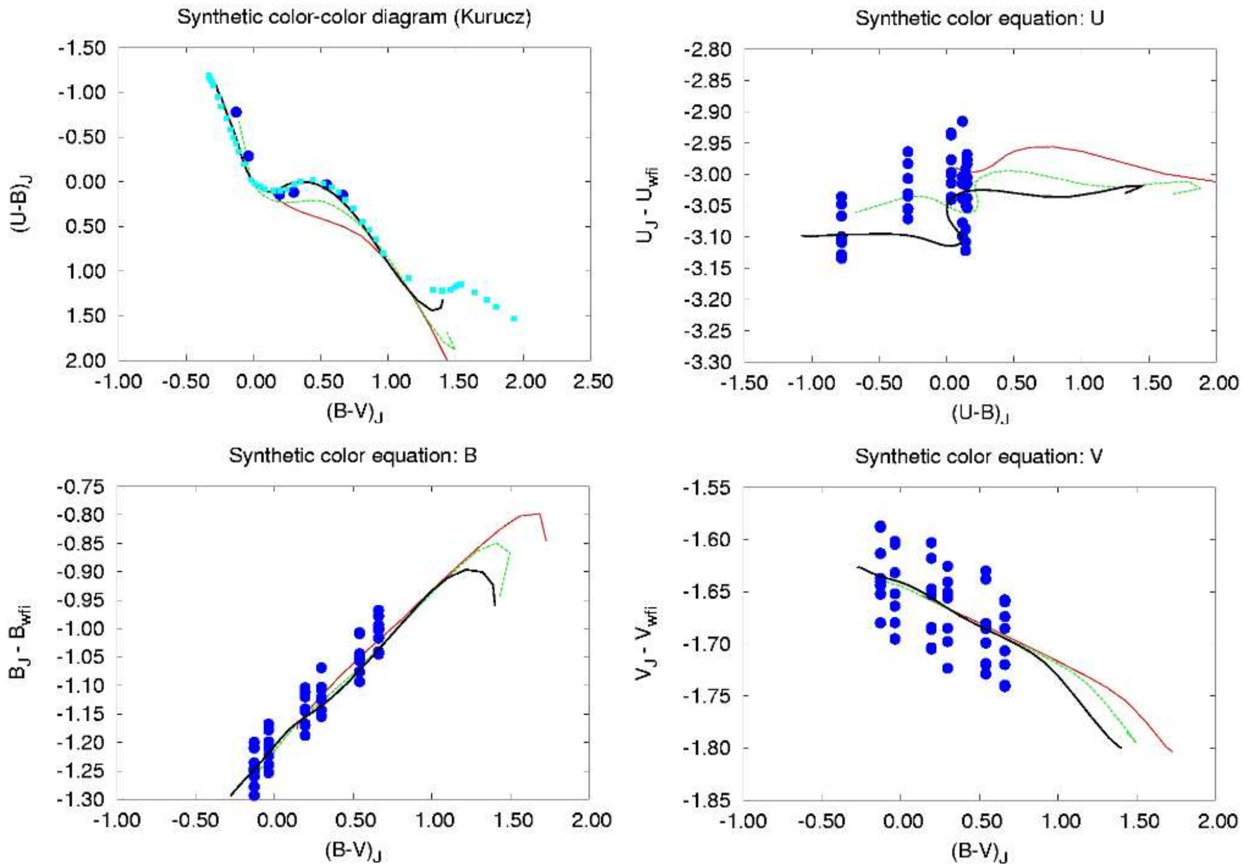

Figure 3.4: Same as Figure 3.2 but with the data of the observations of Ru149 in all chips. The rms residuals from linear colour equations are 0.034, 0.029, and 0.040 for V, B, and U respectively.

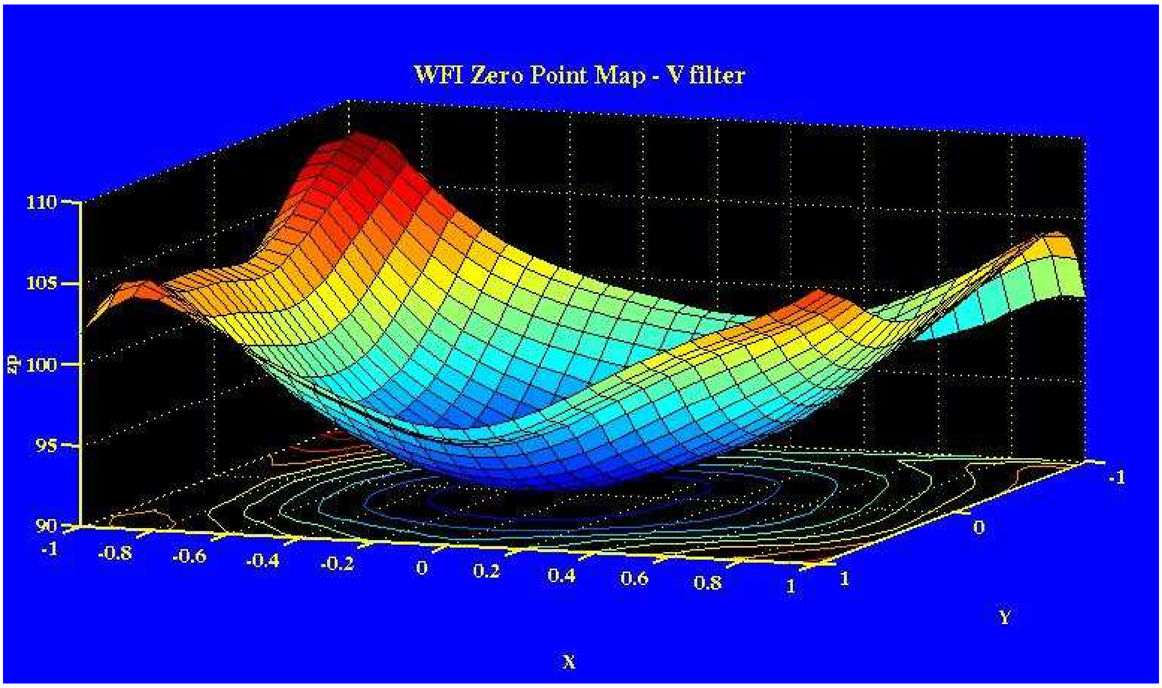

Figure 3.5: Zero point variation of the WFI mosaic for the V filter. The surface represents the percentual variation of the zero point as a function of position. Lower values means that the magnitudes of stars which were measured at those positions (near the center of the mosaic) needs to be made more negative (brightened).

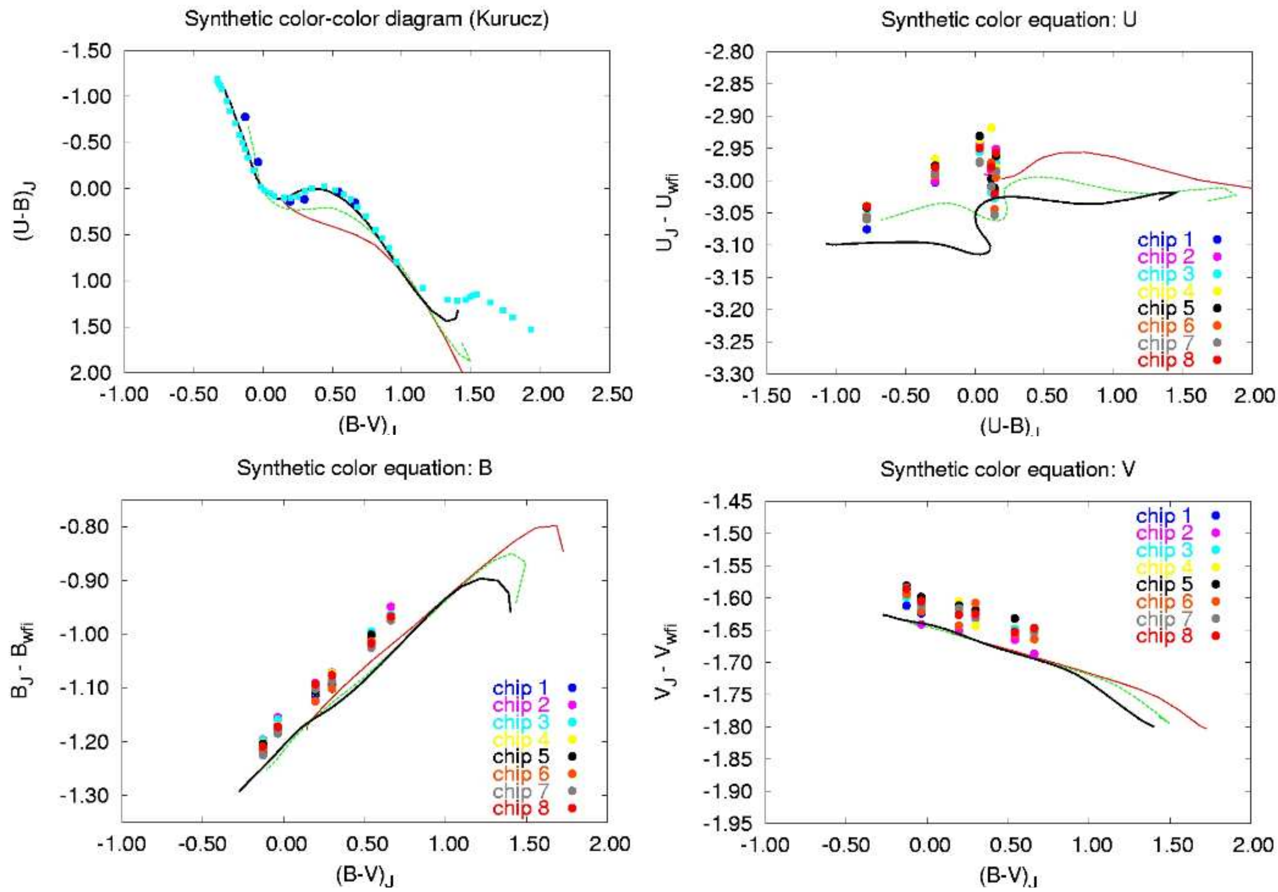

Figure 3.6: All chips data corrected for zero point variations using the method described in the text. The residuals are now 0.009, 0.010, and 0.014 in V, B, and U respectively.

Chapter 4

Slitless spectroscopy with WFI

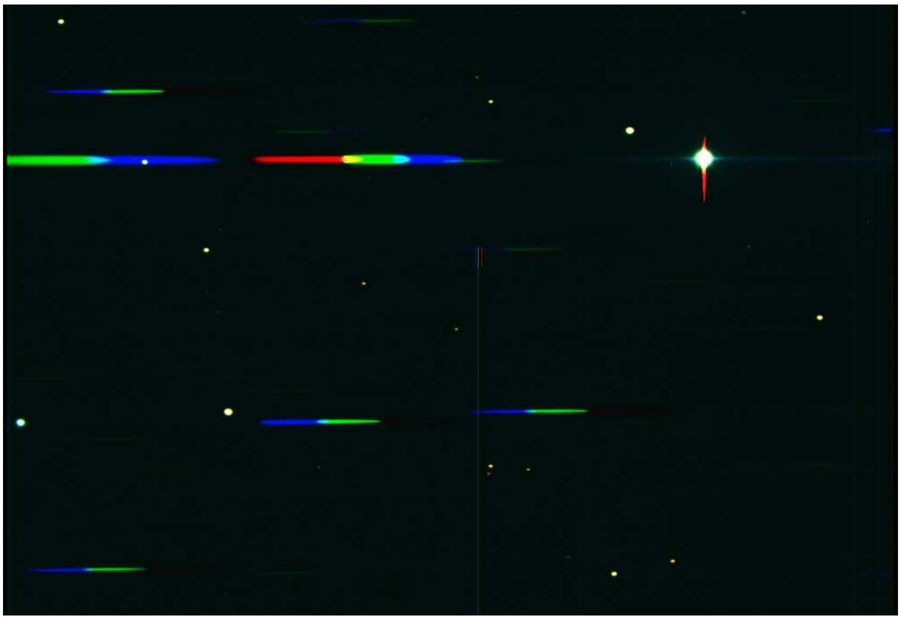

Figure 4.1: Portion of chip 51 showing a stellar field image with grism and filters B/V/R.

In addition[1] to the imaging mode, a slitless spectroscopy mode exists for WFI. This is accomplished by the installation of a grism in front of the WFI triplets. The combination of the wide field of view, the grism, and the simultaneous availability of the whole set of WFI filters, make this a unique instrument in the southern skies. Note that the WFI in grism mode is only offered in visitor mode. **It is not possible to switch between imaging and slitless spectroscopy modes during the night.**

In a preliminary ESO internal report by Hermann Boehnhardt, the following case was made for the spectroscopic mode of the WFI. This mode allow survey work for stellar, nebular objects, and galaxies with special characteristics. The main goal would be the registration and identification of such sources by their spectral signatures to establish population and distribution statistics and to prepare in-depth follow-up investigations by dedicated research programs with other telescope and instruments.

[1] This section is based on a more extensive report of the commissioning of the grism that appeared in The Messenger [22].

Table 4.1: Summary of properties of the WFI grism.

Grism	Blaze wavelength	Wavelength Range		Dispersion		IQ	Resolution
		nominal	measured	nominal	measured		
	nm	nm	nm	nm/pix	nm/pix	pix	nm
R50	600	650–850	420–900	0.811	0.691	6.3	4.4

A rough estimate of the gain in sensitivity for the WFI at the MPG/ESO 2.2-m telescope as compared to objective prism spectroscopy at Schmidt telescopes gives: gain in aperture by a factor of 4–5, gain by CCD sensitivity as opposed to photographic emulsion by a further factor of 20 or more, for a total factor of 100 in sensitivity gain. The advantage of the WFI in spectroscopic mode with respect to standard CCD spectrographs at 2-4m class telescopes is its much larger field of view, and its ability to obtain spectra of all objects therein at once.

In the preliminary draft mentioned above the following areas of research were identified:

- search for stars with emission lines
- search for stars with peculiar molecular lines
- search for white dwarfs
- detection of stars with strong magnetic fields
- detection of Hα emission line stars in dark clouds
- search for Herbig-Haro objects
- search for stars at large distances above the galactic disk
- detection of extragalactic HII regions and planetary nebula
- detection of objects without obvious spectral lines
- membership in distant galaxy clusters
- search for emission line galaxies and quasars
- detection of galaxies with peculiar continuum at high redshift
- search for lensed quasars

The potentialities of the instrument can be gauged by looking at previous survey results [15], where a 61 degree area is covered but with an effective exposure time of only 34s to 63s (the WFI in 4 hours integration covers an equivalent volume): spectra for 600000 objects is obtained, with approximately 800 emission line galaxies, and 90 quasars. The same authors in a deeper survey, with 300s effective exposure time, and 1.10 square degrees effective area, find approximately 50 low redshift emission line galaxies, 9 high redshift ($z > 2.7$) quasars [16].

4.1 Image quality and calibration

In table 4.1 we present a summary of simulated and measured properties of the available grism. The wavelength range has been defined as that portion over which the efficiency is above 25% of the measured peak efficiency, and has been read directly from the measured response curves for the R50 grism.

4.1.1 Simulated optical properties

Because of the geometry of the WFI instrument, the dispersing element have to be placed in the converging beam were they induce larger aberrations. See the classical papers by Hoag and Schroeder 1970 and by Bowen and Vaughan 1973 [11, 6]. Thus, a careful optical analysis had to be conducted.

A technical/feasibility study was performed in 1998 [10]. It contains simulations of the optical properties expected with the two available grisms at the time. Because of its superior efficiency at all wavelengths, and order rejection properties, we offer only the R50 grism.

4.1.1.1 R50/6000 Grism.

The dispersion of this prism was calculated to be 54 nm/mm, or 0.811 nm/pixel. The geometric encircled energy plots show a predicted 80% monochromatic imaging quality of 5.6, 5.6 and 6.4 pixels, for each wavelength, to be convolved with an assumed telescope PSF of 3 pixels. The global image quality will amount to 6.3, 6.3, and 7.0 pixels respectively when the external seeing is 0.65 arcsec. The nominal spectral resolution is then around 5.1, 5.1, and 5.7 nm for $\lambda = 650$ nm, 750 nm, and 850 nm, respectively (in general, the resolution in slitless spectroscopy depends on the seeing and will be degraded in case of poor seeing conditions). Notice that the actually measured dispersion is slightly lower than the nominal value.

Technical data:

- Corning B1664 prism of 2.49 degrees.
- replica 53.33 gr/mm with 3.42 blaze angle
- triplet properties: 54 nm/mm with blaze wavelength at 590nm

The optical simulations show that CCD tilt improves the image quality drastically, with image below 2 pixels, meaning 2.9nm over the full field. However, as of this writing there are no plans to offer a setup with a tilted CCD.

4.1.2 Measured optical properties

Because we did not tilted the CCD we thought it important to perform actual measurements regarding the degradation of image quality.

Figure 4.2 shows the image quality with the R50 grism together with the B filter. The image confirms the shapes predicted by the simulations. The nine images are extraction of 0th orders in different parts of the mosaic: the top row show images extracted in the upper parts of chips #51, #52, and #53; the middle row show images extracted at the bottom of the same chips; and the bottom row show images extracted at the bottom of chips #56, #55, and #54.

Figure 4.3 shows a better example of the achievable quality. It shows extracts from a 900s image through the R50 grism and the medium band filter MB516. The arrangement in the montage is as before. The numbers are the FWHM of the vertical distribution of light at the center of each spectra, measured in pixels (1 arcsec = 4.2 pix).

Another important property is the ability to superimpose dithered images. What we did was to use the astrometry tasks of the IRAF mscred package to superimpose the zeroth

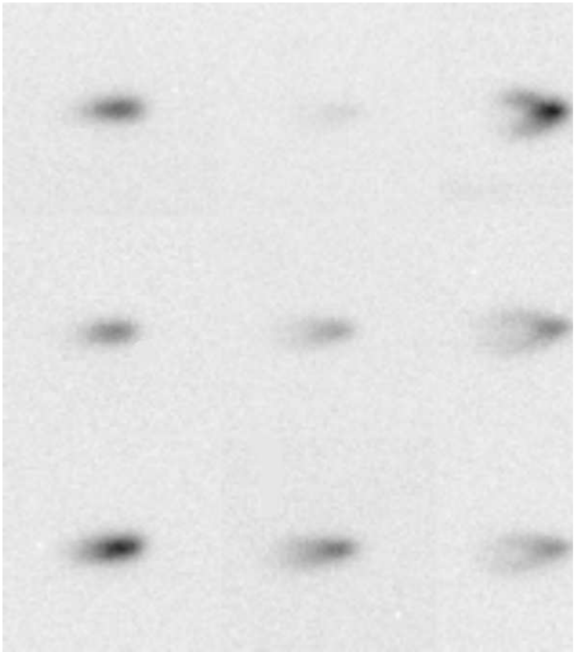

Figure 4.2: Shape of the zeroth orders as measured with the R50 grism and the B filter. The scale is such that the vertical and horizontal distances between images correspond to 60 pixels or 14 arcsec.

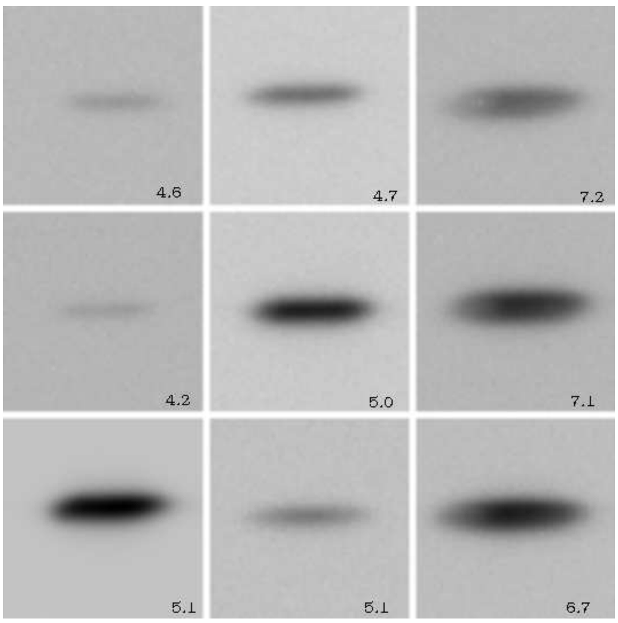

Figure 4.3: Shape of the first order as measured with the R50 grism and the MB516 filter. Scale set in same way as in previous figure.

Table 4.2: Efficiencies of the WFI + grism (counts in first order).

Filter	ETC counts e^-	R50 counts e^-
B	222	108
V	248	150
R	543	429
I	371	176
White	1729	≈1100

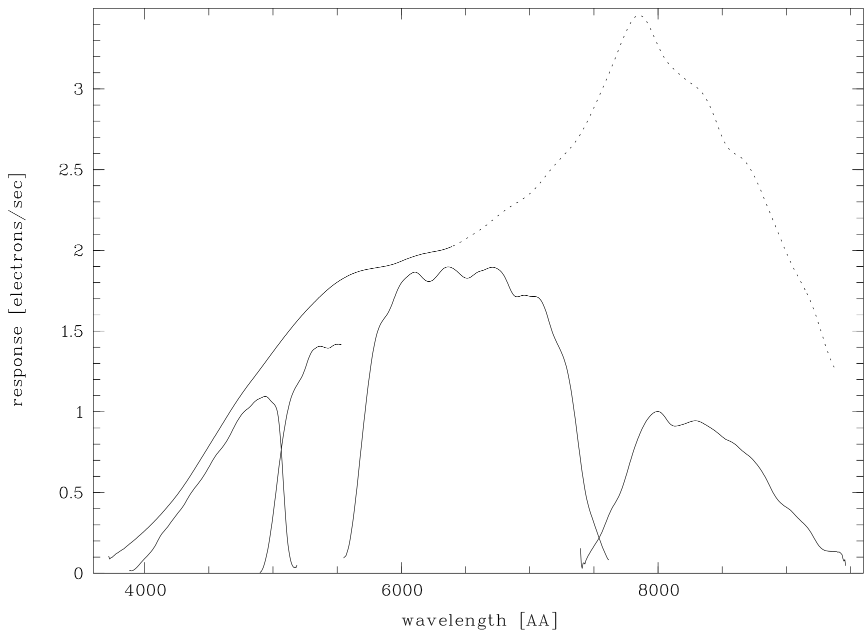

Figure 4.4: Response curves for the R50 grism with no filter, and with the B, V, R, and I filters.

orders, and then see how well did the first orders matched. We produced an animation that you can see in the web, at the URL
`http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/grism`.
The animation shows a portion of three dithered images centered on a bright quasar. In it, one can see that the emission lines superimpose rather well.

4.1.3 Flux calibration and efficiencies

Table 4.2 summarizes the data on the overall response of the telescope plus grism plus WFI. The numbers reported are the integrals over the response curves. They assume a source having a flat spectrum with f_λ = const. $= 1 \times 10^{-16}$ erg s^{-1} cm^{-2} Å^{-1} (corresponding to a Vega magnitude of $V = 18.83$), observed with an exposure time of 1s. For comparison, we list also the count rates estimated by the WFI exposure time calculator for direct imaging in each filter; the ratio between these and the grism counts gives directly the efficiency losses

Table 4.3: Distribution of flux among orders.

Order	Grism R50 B	R
-3	0.1	
-2	0.4	0.8
-1	2.0	1.6
0	7.0	2.3
$+1$	100.0	100.0
$+2$	29.0	0.4
$+3$	2.0	
$+4$	0.4	
$+5$	0.1	

Table 4.4: Global dispersion of the WFI grism.

Grism	Measured Dispersion nm/pix	Spatial Variation %	pix
R50	0.691		N/A

due to the grism.

Figure 4.4 show the grism response curve obtained by observing the HST flux standard GD108. The units of the ordinates are electrons/pixels.

Notice that above 640 nm the curve for no filter ("white") is heavily contaminated with light from the second order (dotted lines). As soon as filters are used, no such contamination occurs since the orders will always be spatially well separated.

4.1.3.1 Diffusion of flux into adjacent orders

Table 4.3 shows the relative flux distribution among the different orders. The 1st order has always been set to 100. Notice that more than 90 % of the flux is in the first order (in the R band). This results in an almost total lack of 0-th order images when observing with some red medium band filters, a fact that could somewhat complicate the wavelength calibration (but see our suggestions below on observing strategies).

4.1.4 Wavelength calibration

Table 4 summarizes the measured dispersions of the WFI grism. The wavelength calibrators used were the Seyfert 1 galaxy Mrk1239, which shows several emission lines over the entire spectral range, and a number of M-type stars with prominent TiO absorption bands. The object was placed near the center of the array, and in several positions near the corners and edges. In the absence of accompanying direct images, the 0-th order centroids were used to define the wavelength zero-points. We found that the true zero-points varied by quite a bit, up to ~ 3 pixels between different locations on the array in a nontrivial manner, probably as a result of optical distortions induced by the grism. Unless a much more detailed investigation shows how to model these distortions, this effect ultimately limits the achievable wavelength calibration accuracy to $\sim \pm 15$Å or so.

The dispersion relations of the grism is well described by a 2nd order polynomial (see Fig. 4.5). Given the substantial zero-point uncertainties, in most practical cases it is probably

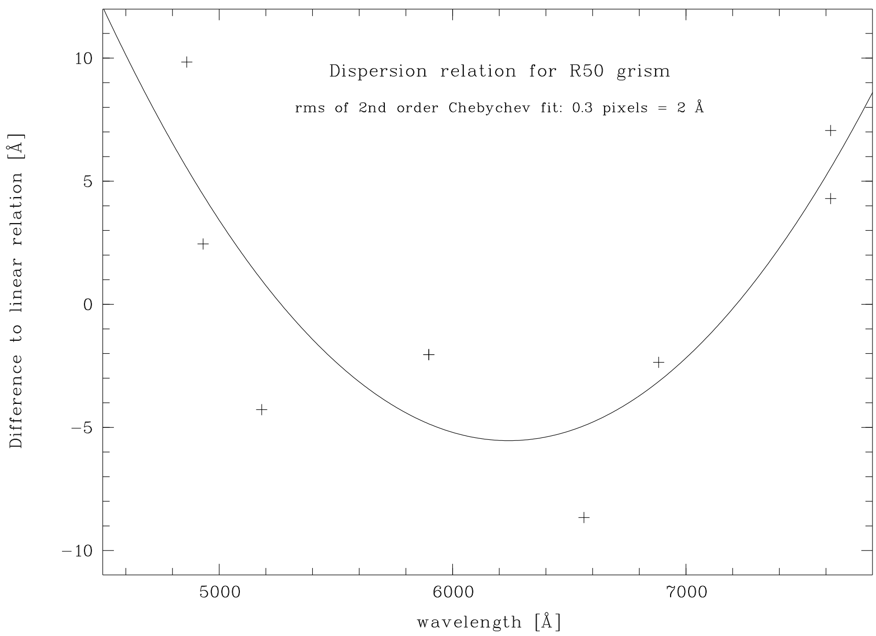

Figure 4.5: Quadratic dispersion solution for the R50 grism.

sufficient to work with a linear dispersion relation, as the maximum systematic error will be substantially less than the zero-point variations except for white light (no filter) images, which we strongly discourage anyway.

4.2 Observing

4.2.1 Example spectra

We present in this section a few real extracted and calibrated spectra so that future users obtain a better idea of the capabilities of the instrument.

4.2.1.1 Flux standard star

Figure 9 shows the HST flux standard GD 108, a hot sub-dwarf with distinct Balmer absorption lines, observed with the WFI R50 grism and the B, R, and I broad band filters. Integration time for each of these exposures was 100 sec.

Slitless spectroscopy has one rather obvious property which is nevertheless worth recalling: Slit losses are naturally avoided as there is no slit, and the extracted spectra are therefore easily placed onto a proper (at least relative) flux scale.

4.2.1.2 Comparison between a slitless and a slit spectrum

Figure 10 shows the extracted slitless spectrum of our wavelength calibrator Mrk 1239 (plotted in black), obtained with an old grism not offered anymore. The figure illustrates the

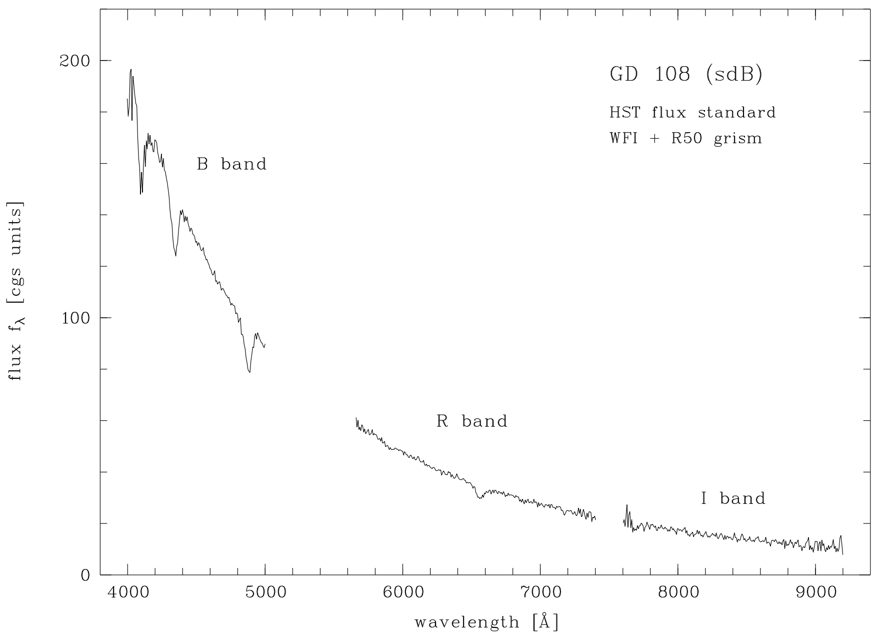

Figure 4.6: Spectra of the HST standard GD108.

potential of WFI for slitless spectroscopy. This is contrasted with a slit spectrum of the same object taken in 1997 with the ESO 1.52m telescope and the Boller & Chivens spectrograph (upper spectrum plotted in red). The original B&C spectrum has somewhat better spectral resolution, and we therefore smoothed it to approximately the same resolution as the WFI spectrum. The resemblance of the two datasets is striking and illustrates the fidelity by which spectral information can be extracted from WFI slitless spectroscopy.

4.2.2 Hints for observing

The Wide Field Imager in its slitless spectroscopic mode is a powerful and almost unique instrument to conduct surveys for objects with characteristic spectral signatures. This final section is meant to help interested potential users planning such a survey, and to provide some guidelines for data reduction.

4.2.2.1 Always observe with a filter

Without filter, there are several substantial drawbacks that will severely reduce the usefulness of your data:

1. The background would be prohibitively high for deep surveys as all the sky contributions over the entire spectral range go into each pixel.

2. The spectra are much longer, and the losses because of overlapping spectra will be substantially increased.

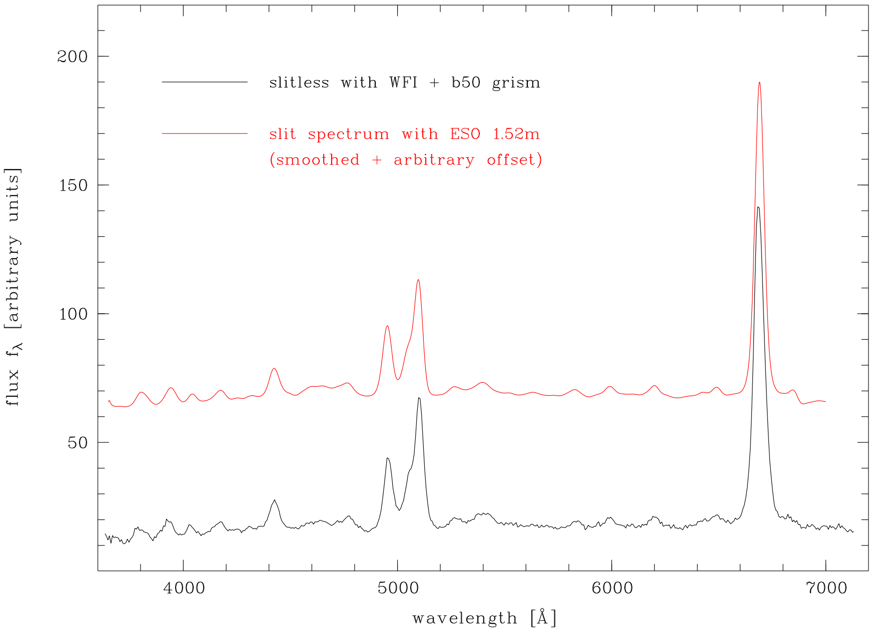

Figure 4.7: Spectra of the Seyfert 1 galaxy Mrk 1239. Lower spectrum in black: WFI slitless (with a very poor grism that is not offered anymore); Upper spectrum in red: slit spectrum taken with ESO 1.52 m telescope, and Boller and Chivens spectrograph, with arbitrary offset in flux only.

3. Contamination by 2nd order spectra limit the exploitable spectral range to below ~ 650 nm.

4.2.2.2 Always obtain a direct image of your field

Although it is technically possible, in principle, to use the 0th orders to define objects and determine wavelength calibration zero-points, we *strongly* recommend to use paired direct images to this purpose. This recommendation is based on the experience collected in the course of the Hamburg/ESO survey, a large quasar survey based on digitized objective-prism Schmidt plates [21] (see also Reimers & Wisotzki 1997). These papers also outline a working strategy for object definition, extraction and wavelength calibration for slitless spectroscopy in general.

The suggested approach has important advantages:

1. Object definition and classification is much easier and more reliable on proper direct images with no interference from spectra. Photometry and astrometry are also more accurate.

2. Once an astrometric transformation from direct to spectroscopic image is established, one can *a priori* identify spectra that suffer from contamination from other objects (either 1st or other orders). In particular, the superposition of 0th and first orders from different sources can mimic emission line objects; this can be readily recognized with a direct image.

3. Especially with certain medium-band filters, the 0-th order can be so faint that it is barely detectable except for the brightest sources.

The direct image should be sufficiently deep as to allow the detection of all objects of interest. In certain applications, this may require a pretty long integration in the same filter band(s) selected for spectroscopy. Consider for example a search for continuum-free emission-line objects with medium-band filters. Such objects are effectively point sources in the spectral images, so in order to reach similar depth in the direct image, almost comparable exposure times are needed.

4.2.2.3 Take flat fields in all filters

At the same time that the direct images are taken one should obtain flat fields in all the filters that will be used. The flattening of this kind of observations is an unsolved problem which will require further experimentation: the pixels exposed by the spectrum of an object each receive a different wavelength, monochromatic light, due to the object. When a flat field is obtained those same pixels are illuminated by broad band, or at best medium or narrow band light *of the same spectral composition throughout*.

4.2.2.4 Take rotated images in crowded fields

It is important to obtain images in at least two rotations if source crowding is important. Currently, the system allows only small rotations, less than 10 degrees, but this is more than enough to move zeroth and higher orders of neighboring objects from the areas of interest. The rotations are specified in the acquisition template of the respective observing block but needs to be applied manually at the telescope. With these small rotations the autoguider can still be used.

Chapter 5

VLT style observing with WFI

Like at the VLT, the NTT, and the 3.6-m Telescope, observations with the WFI (Wide Field Imager) at the MPG/ESO 2.2-m Telescope are made using the concept of Observation Blocks (OBs). The WFI imager lends itself well to this mode of observing as it is conceptually a simple instrument, and WFI observations are usually of a very repetitive nature. Therefore, using Observation Blocks at the WFI permits the observing efficiency to be maximized.

An OB is the smallest schedulable observation unit within the ESO *Data Flow System* (see URL: `http://www.eso.org/org/dmd/`). An OB contains a sequence of high level operations, called *templates*, that need to be performed sequentially and without interruption in order to ensure the scientific usefulness of an observation. An OB consists of four elements, namely a Target Package, a Target Acquisition Template, an Observation Description (which can consist of several science or calibration templates but normally not both), and a Constraint Set. Every OB must contain one and only one target acquisition template. That is, while dithering about one reference position is possible within one OB, observations of different fields require creation of separate OBs.

There also exists a category of Calibration OBs (CalOB) which require no target acquisition template to be attached; these are used for flat-field images, biases and darks. By means of the Constraint Set, Service Mode users can constrain the timing of the observations, the meteorological conditions under which they are executed, etc.

Execution of a typical OB might consist of the following steps:

Execute acquisition template:

- Preset to Target
- Wait until autoguider is activated

Execute Observation Description:

- Acquire 3 B-band images without offsetting
- Acquire 5 dithered V-band images

A *template* is a high-level data acquisition operation. Templates provide the means to group commonly used procedures into well-defined and standardized units. They can be used to specify a combination of detector, instrument, and telescope configurations and actions. Templates are executable if embedded in an OB or CalOB. They have input parameters described by a *template signature*.

The values used in the template are mostly set by the observer when s/he is preparing OBs using P2PP. Other non-user serviceable parameters are hard-coded within the template Sequencer Script, which actually executes the OBs (see below).

A template consists of the following components:

- Sequencer Script
- Signature File
- Parameter GUI

The Sequencer Script (also called *a sequence*) is a `Tcl/Tk` program, which sends commands to the OS (Observation Software), using the parameters contained in the OB. The OB to be executed is selected (using the P2PP panel) and fetched by BOB (Broker of Observation Blocks). BOB is the tool which deals with the execution of OBs (if interested in technical background information, the reader is referred to the *BOB User's Manual*).

The definition of these parameters (names, types, default values and allowed ranges) is contained in the so called *Template Signature File* (TSF). Each template has its own signature file. When preparing an observation description with P2PP, the observer is actually using this file. The number and type of parameters change according to the complexity of the template. For instance, all acquisition templates deal mostly with telescope parameters only (auto-guiding, etc.).

Finally, the Template Parameter GUI is the graphic interface which appears in the P2PP panel when preparing an observation description. This panel changes according to the number of parameters that the user is allowed to edit. The P2PP GUI is the *only* point of contact between users and Observing Templates or Observations Blocks. Users will never need to see a Sequencer Script or a Template Signature File. They merely fill in the fields presented to them in the P2PP GUI.

Table 5.1 provides a quick reference to the templates implemented and supported at the time when this version of the WFI Handbook was issued. *Before starting with the creation of OBs, you should check in the* WFI WWW *home page (*URL: `http://www.ls.eso.org/lasilla/sciops/wfi/`*) that you are using the most recent version!*

The names of the templates have been set according to the ESO Data Interface specifications (see URL `http://archive.eso.org/DICB/`). All the templates' names start with the string `WFI` which is then hierarchically followed by:

1. either `img` or `spec` to denote imaging or spectroscopic mode. Only `WFI_cal_Darks` and `WFI_cal_FocusSeq` contain neither of these tokens because for bias, dark and focus exposures the optical configuration is irrelevant.

   Imaging and spectroscopy templates of the same kind differ only marginally (see Sects. 5.2-5.4).

2. one of `acq`, `obs`, or `cal` to distinguish between acquisition, science, and calibration templates, respectively.

3. a string providing a short mnemonic description of the purpose of the template.

(This key is useful for identifying in the Table of Contents on p. 1 candidate observing templates for a given project.) Note that the user gets a list of these names in a P2PP pull-down menu: s/he never needs to type these names.

Table 5.1: WFI templates quick reference

Task	**Template to use**	`<imagename>`
ACQUISITION TEMPLATES		
Telescope preset for imaging	`WFI_img_acq_Preset`	(no image)
Telescope preset for spectroscopy	`WFI_spec_acq_Preset`	(no image)
Telescope preset and move object to nearest detector gap (imaging)	`WFI_img_acq_MoveToGap`	`WFI_AcqGapIma`
Telescope preset and move object to nearest detector gap (spectroscopy)	`WFI_spec_acq_MoveToGap`	`WFI_AcqGapSpec`
Telescope preset and move object to pixel coordinates (imaging)	`WFI_img_acq_MoveToPixel`	`WFI_AcqGapIma`
Telescope preset and move object to pixel coordinates (spectroscopy)	`WFI_spec_acq_MoveToPixel`	`WFI_AcqGapSpec`
SCIENCE TEMPLATES		
Imaging	`WFI_img_obs_Dither`	`WFI_Ima`
Spectroscopy	`WFI_spec_obs_Dither`	`WFI_Spec`
CALIBRATION TEMPLATES		
Darks	`WFI_cal_Darks`	`WFI_Dark`
Focus sequence	`WFI_cal_FocusSeq`	`WFI_FocSeqIma`
Imaging dome flat fields	`WFI_img_cal_DomeFlat`	`WFI_FlatDomeIma`
Imaging sky flat fields	`WFI_img_cal_SkyFlat`	`WFI_FlatSkyIma`
Spectroscopic dome flat fields	`WFI_spec_cal_DomeFlat`	`WFI_FlatDomeSpec`
Spectroscopic sky flat fields	`WFI_spec_cal_SkyFlat`	`WFI_FlatSkySpec`

Notes: `img` and `spec` denote imaging and spectroscopy templates, respectively. `<imagename>` is the root of the name of the raw files created by a given template (see Sect. 5.5)

When using the WFI templates, the user will automatically get the default values for the parameters, unless s/he actively changes them. However, some parameters have NODEFAULT as their default values. Such parameters must always be changed to an actual value, otherwise P2PP will report an error. In Sects. 5.2-5.4:

$1 \leq \jmath \leq 10$ indicates that the parameter can be any integer between one and ten,

$1 \leq \Re \leq 10$ indicates that the parameter can be any real value between 1 and 10.

Finally, the template descriptions given below make use of certain seemingly cryptic terms like INS.FILT1.NAME (the filter name), TEL.RETURN (telescope return to initial position?) or DET.WIN1.UIT1 (integration time). They can be safely treated as variables with unknown value. The names only matter to those users, who are curious enough to read the actual OB files they have created. Normally, the P2PP GUI should make this superfluous. Some of these terms occur also (usually in slightly modified format) in the FITS headers of the images eventually obtained.

Table 5.2 gives approximate overheads for the WFI templates.

5.1 General rules and advice

5.1.1 Support

ESO provides dedicated support during the preparation of OBs (`usd-help@eso.org` for Service Mode programs and SciOps members at La Silla for visitors). Nevertheless, the

Table 5.2: WFI template overheads

Pointing telescope	• Over large angles ∼ 3000″/sec • Typical pointing time between 30 seconds and 2 minutes
Changing filter	45 seconds + 2.5 seconds × difference in position number of filters. For example, chnging from position #4 to position #12: 45s + 2.5×(12-4)=65 seconds
Software overheads	• No preset, and no change of filter: 5 seconds • Preset within same field (i.e. only small telescope offsets), no change of filter: 25 seconds.
Acquire guide star[1]	<= 1 minute
Detector readout	27 seconds
File transfer to instrument control workstation and RTD	45 seconds: 27 seconds + 18 seconds
Determination of telescope focus	<= 12 minutes
MoveToGap template MoveToPixel template	2×(Exposure time + 45 seconds) for readout and transfer + ∼1 minute, to find star and set coordinates.

Notes: 1. If you have `Combined Offsets` set to `F`, as when you have offsets larger than the tracker chip, this overhead applies for each image within your dither sequence.

responsibility for the correctness of the provided OB parameters is exclusively the one of the users.

Sect. 5.8 offers a WFI-specific P2PP tutorial. Comprehensive checklists for the definition of WFI observing programmes to be executed in Visitor Mode and Service Mode, respectively, are provided in Sects. 5.6.1 and 5.6.2. First-time users are advised to exercise with the tutorial before defining their real OBs. The check lists should always be useful.

Note that OBs, which pass the P2PP verification tool without any problems, may still be far from the goal of being the basis for successful observations. Such potential pitfalls are compiled in Sect. 5.6.

5.1.2 Accounting of observing time in service mode

The observing time allocated by the Director General to Service Mode programs is the sum of shutter-open time and operational overheads. Use the report utility of P2PP for estimating them.

5.1.3 Visitor and service modes

Software-technically, there is absolutely no difference between the execution of OBs in Visitor and Service Mode.

However, in Visitor Mode on-line modifications of OBs are easily possible (but it still pays off to prepare them in advance and as carefully as possible!). In contrast, OBs submitted for execution in Service Mode are executed by ESO as prepared by the user. ESO will not apply any modifications (e.g., to reduce disturbing effects caused by bright stars).

5.1.4 Complexity and scheduling of observation blocks

Unless the options provided by the Constraint Set are used, users have no way to control over when and in which order their Service Mode OBs are executed.

Technically, it is possible to pack so many templates into one OB that their total execution time matches the visibility of the target field. However, in Service Mode, this would have catastrophic consequences because the 'tiling' of the nights with OBs is evidently much more efficient if each OB is kept as short as possible. Thus, the schedulability of an OB, i.e. the probability of its execution, scales roughly with the inverse of its execution time.

If the scientific objectives of a Service Mode observing programme stringently require OBs with execution times (exposure times plus operational overhead) above one hour, you have to request a waiver of this limit by sending e-mail to `usd-help@eso.org`.

Note also that there are many additional parameters governing the scheduling of OBs in Service Mode. Among those under direct control of the users, the Constraint Set is the most important one. E.g., the number of new moon nights with a seeing of better than $0.5''$is simply very small (if not zero).

In only slightly modified form, the same arguments apply to Visitor Mode as well: The possibility of unpredictable events (changing weather, temperature variations requiring re-focusing, technical problems, etc.) strongly argues for maintaining operational flexibility by using OBs with short execution times.

5.1.5 Operator interventions, etc.

This document occasionally describes operator actions, etc. This is done to allow a better understanding of how the OBs are executed in practice. There is neither the need nor the possibility to specify any of them with P2PP. It is fully sufficient to fill in the template forms supported by P2PP. The operations procedures established by the Observatory for each observing template take care of the rest.

Conversely, templates for which specific operator actions are not mentioned are executed fully automatically.

5.1.6 Embedded comments

P2PP permits comments to be inserted in various sections of the OBs. Service Mode users are strongly encouraged to exploit this possibility of explaining to the operations staff the scientific objectives of the observations and the exact conditions to be satisfied for their execution.

5.1.7 Parameter ranges and explanations

While there is no substitute for reading this handbook, the P2PP GUI provides admissible ranges for parameter values and brief explanations of parameter names when the corresponding fields are pointed at with the cursor.

5.1.8 CalBlocks, ObsBlocks and template types in P2PP

Unfortunately, the P2PP terminology is not fully unambiguous. On its main panel, P2PP distinguishes between ObsBlocks and CalBlocks. The only – but important – difference is that ObsBlocks also contain object-specific parameters (most notably: coordinates) whereas CalBlocks do not and are, therefore, executed at daytime for calibration purposes. The rules for their usage are:

CalBlocks are *only* to be used when the specification of RA and DEC does not make sense, i.e. for bias, dark, dome flat field, twilight flat field, and focus exposures. Note also that CalBlocks are *always* to be used for these purposes.

ObsBlocks need to be defined for *everything else*, i.e. incl. astrometric standards, photometric standards, and spectrophotometric standards.

In the OB panel, P2PP foresees four generic templates types: `acquisition`, `science`, `calib`, and `test.` The types of the available WFI templates are given in Table 5.1. Note that templates of type `test` are not offered to users. As of writing, the P2PP OB panel lists *all* templates, regardless of their type, under both ObsBlocks as well as CalBlocks (with the exception of the acquisition templates which are only listed under ObsBlocks). As a result, P2PP happily lets users combine science exposures on the sky in imaging mode and, say, spectroscopic dome flats into one OB. Evidently, such OBs do not make sense and will, therefore, be rejected. Operationally, only the following choices of template types are supported:

In CalBlocks: `calib` templates;

In ObsBlocks: `acquisition` templates and `science` templates. (Bias exposures may be included but users are discouraged to do so because of the negative impact on the observing efficiency.) Observations of standard fields, although used for calibration purposes, require `science` templates.

(Observations of 'empty' fields in the sky for flat fielding can be defined by means of `ObsBlocks` with `acquisition` and `science` templates. But note the discussion in Sect. 3.2.2 of the usefulness of such observations.)

5.1.9 User supplied filters

User supplied filters are selected by choosing the 'Special' filter. The 'Special' field can be edited and any filter name entered (must not be the same name as the one of an already existing filter).

The usage of non-ESO filters with the WFI requires prior approval by La Silla SciOps. Users are, therefore, urged to read the Sect. 2.3.2 and to send e-mail to `lasilla@eso.org` before submitting a proposal depending critically on non-ESO filters.

5.1.10 Exposure type

All science templates have a pull-down menu with the following options:

OBJECT
SKY
STD
FLUX,STD
ASTROMETRY
OTHER

There is NO DEFAULT and the selection of one such entry is mandatory (enforced by the P2PP verification tool). For a pointing to a a specific scientific target use OBJECT. For an empty sky region one would use SKY. The difference between STD and FLUX,STD is that the former applies to all conventional photometric standards whereas FLUX,STD only applies to spectrophotometric standards.

5.2 Acquisition templates

Acquisition Templates (`acq`) determine how a target field is acquired by the telescope. They are attached to specific Observation Blocks during the OB building process described in the *P2PP user's manual*. Telescope *presets* can **only** be performed using acquisition templates, observation templates can merely *offset* the telescope (by up to 9999″).

All OB's must have **one and only one** acquisition template attached. The exception to this rule is the 'Calibration OB' (CalOB), which is a special OB that requires no target package or acquisition template. After the successful execution of the acquisition template, sequential execution of all subsequent templates contained in the OB commences automatically.

In all WFI acquisition templates, a Boolean switch can be set to specify whether or not a guide star shall be used for the OB, to which the acquisition template belongs. The default is `True` because the drive of the 2.2-m Telescope has a periodic error in alpha with a 4-minute period and a peak-to-valley amplitude of 1.″2 (see Sec. 2.1.1 for details). However, for OBs with both very short exposure times (less than 15 seconds to insure no image degradation even in the best seeing conditions) and a short total execution time, the detrimental effect of this wobbling may weigh less than the time losses due to the guide star acquisition (typically between 30 sec and 2 min). Only in this case, and for the observations of standard stars `False` might be the better choice.

Some WFI acquisition templates contain a second Boolean switch labeled "New preset flag". If set to `True`, a normal preset will be executed, even if the coordinates of two consecutive OB's are the same. Depending on the observing templates contained in the first OB, there will be some offset. If the next observations are to be made as nearly as possible at the same position as before, this switch should be set to `False`. Then, no telescope preset will be executed. **Very important:** P2PP does not currently support several OBs to be linked. Service Mode users have, therefore, no control over the order in which OBs are executed (they may be spread over many nights) and **must not** set this switch. If they do, the field of the previous OB will be re-observed, which normally belongs to a different project!

The counterpart of the "New preset flag" in acquisition templates is the "Return to origin" flag in science templates: When the latter is set to `True`, the telescope returns after the last exposure in a template to the original position, and the next OB can start from there immediately without new guide star acquisition if it has the "New preset flag" set to `False`.

When filling in the target-related fields in the OB form of P2PP, awareness of the following can be useful:

1. Proper motions are to be entered in units of arcseconds per century. (Over a field of view of half a degree, proper motions are normally negligible for all practical purposes.)

2. Differential tracking rates are in units of arcsec/sec.

3. As is clear from the order-of-magnitude difference in the units, proper motions are only used for the conversion of coordinates between equinoxes (or epochs). Conversely, differential tracking rates are only to be specified for rapidly moving targets, i.e. in the solar system.

4. The TCS of the 2.2-m telescope requires that epoch and equinox are equal.

5.2.1 `WFI_img_acq_Preset` and `WFI_spec_acq_Preset`

Label	**Default**	**Values**	**WFI mode**
New preset?	T	T, F	`img, spec`
Acquire guide star?	T	T, F	`img, spec`
RA diff. tracking (arcsec/sec)	0	$-0.25 \le \Re \le 0.25$	`img, spec`
DEC diff. tracking (arcsec/sec)	0	$-0.25 \le \Re \le 0.25$	`img, spec`
Filter	NODEFAULT	Many	`img, spec`
Grism	R50	R50	`spec`
Rotator angle (degrees)	0	-10, 0, 10	`spec`

These acquisition templates preset the telescope to the coordinates of the target associated with the Observation Block. At the end of the execution the operator is requested to find a guiding star and to activate the autoguider (unless the guide star acquisition flag is set to `False`). There is no further operator intervention. No CCD frame is produced by these templates, which are meant to be used to merely preset the telescope to targets which do not require an accurate centering.

Nevertheless, these templates contain a field for the specification of a filter. The reason is purely operational efficiency: The pre-setting of the telescope and the change of filters typically require about the same time. If the filter is specified already in the acquisition template, these two tasks can be executed in parallel. *Note that this gain is lost if the subsequent science template specifies a different filter!*

For moving targets, differential tracking rates can be specified. **Important:** Because differential tracking is actually implemented as differential *guiding*, the guide star selection flag must be set to `TRUE`. For the same reason, combined offsets are not supported but offsets with manual acquisition of a guide star are possible.

In the spectroscopy template, also the grism and the position angle of the Cassegrain instrument rotator can be specified.

5.2.2 `WFI_img_acq_MoveToGap` and `WFI_spec_acq_MoveToGap`

Label	Default	Values	WFI mode
New preset?	T	T, F	`img, spec`
Acquire guide star?	T	T, F	`img, spec`
Filter	NODEFAULT	Many	`img, spec`
Exposure time (sec)	10	$0.5 \leq \Re \leq 60$	`img, spec`
Grism	R50	R50	`spec`
Rotator angle (degrees)	0	-10, 0, 10	`spec`

These templates perform the interactive presetting to a specific pixel position. The purpose of these templates is to allow a disturbingly bright star to be 'dropped down' a gap between the CCDs. However, these templates can also be used to position a source at an arbitrary point on the CCD mosaic.

The execution of these templates consists of four steps:

1. preset to the target coordinates associated with the OB.
2. acquire an image (exposure time and filter are specified), and the TIO will click with the cursor on the bright star to identify its coordinates, and then click with the cursor on the closest gap, in the direction specified by the user, to the bright star.
3. repeat the image acquisition and offset procedure until the desired accuracy is achieved (as no astrometric solution is applied, large offsets may produce an unacceptable error).
4. if the guide star acquisition flag is set to `True`, the TIO will identify a suitable guide star and start the autoguider.

Note that:

- In Service Mode, these templates may be used for moving a bright star into a gap. A finding chart **must** be supplied by the user that clearly indicates the bright star to be positioned on a gap, and has an arrow indicating the cardinal direction (N, E, S, W) in which the star is to be moved (obviously, the telescope will be moved in the opposite cardinal direction). Note that the telescope will only be moved in one direction, and the bright star will be centered on the first gap in that direction.

  In spectroscopic mode, centering a bright object on one of vertical columns does not accomplish much unless an additionally used filter has a very narrow bandwidth.

In the spectroscopy template, also the grism and the position angle of the Cassegrain instrument rotator can be specified.

5.2.3 `WFI_img_acq_MoveToPixel` and `WFI_spec_acq_MoveToPixel`

Label	Default	Values	WFI mode
New preset?	T	T, F	`img, spec`
Acquire guide star?	T	T, F	`img, spec`
Filter	NODEFAULT	Many	`img, spec`
Exposure time (sec)	10	$0.5 \leq \Re \leq 60$	`img, spec`
Desired reference object X Y	4150 3950	$1\ \ 1 < j\ \ k < 8568\ \ 8256$	`img, spec`
Grism	R50	R50	`spec`
Rotator angle (degrees)	0	-10, 0, 10	`spec`

These templates are similar to the MoveToGap templates, but they allow the specification of the target pixel coordinates in the template. These templates should be used when a particular object is to be placed in a particular pixel. The pixel coordinates of the target are specified as two numbers in the coordinate system of the full mosaic. The default value is "4150 3950", the pixel to which the coordinates of the acquisition refer to.

5.3 Science templates

For both imaging and spectroscopy, there is only one science template each.

5.3.1 `WFI_img_obs_Dither` and `WFI_spec_obs_Dither`

Label	Default	Values	WFI mode
Auto-dithering?	T	T, F	`img, spec`
Initial offset value in RA (arcsec)	0	$-9999 \leq \Re \leq 9999$	`img, spec`
Initial offset value in DEC (arcsec)	0	$-9999 \leq \Re \leq 9999$	`img, spec`
List of tel RA offsets (arcsec)	0	$-9999 \leq \Re \leq 9999$	`img, spec`
List of tel DEC offsets (arcsec)	0	$-9999 \leq \Re \leq 9999$	`img, spec`
Combined offsets?	T	T, F	`img, spec`
Return to origin?	T	T, F	`img, spec`
Filter	NODEFAULT	Many	`img, spec`
Sub-exposure time (sec)	NODEFAULT	$0.1 \leq \Re \leq 3600$	`img, spec`
Number of sub-exposures	NODEFAULT	See Sect. 5.3.1	`img, spec`
CCD binning mode	1x1	1x1, 2x2, 3x3	`img`
	1x1	1x1, 2x2, 3x3, 1x2, 1x3	`spec`
Observation type	NODEFAULT	See Sect. 5.1.10	`img, spec`

These templates take SEQ.NEXPO normal exposures through filter INS.FILT1.NAME with an exposure time of DET.WIN1.UIT1 seconds. Between one exposure and the other the telescope is offset in RA and DEC depending on the value selected for the Boolean switch Auto-dithering.

- **Auto-dithering** or you can define your own dithering pattern.
- **Initial RA offset** Value of RA offset to be applied before proceeding with the selected dither pattern and before the first exposure. Does not count for the return to origin flag, that is, if return to origin is set to T the telescope will return to the position it was after this offset was applied.
- **Initial DEC offset** Value of DEC offset to be applied before proceeding with the selected dither pattern. Does not count for the return to origin flag, that is, if return to origin is set to T the telescope will return to the position it was after this offset was applied.
- **List of RA offsets** Values of RA offsets to cycle through after the initial RA offset is applied. Offsets are relative to the last position.
- **List of DEC offsets** Values of DEC offsets to cycle through after the initial DEC offset is applied. Offsets are relative to the last position.
- **Combined offsets.** Do you want the autoguider try to follow the guide-star when you offset? This is much more efficient, but for large offsets this should be set to `F`, as the

guide-star could fall outside of the tracker chip after the offset and a new one would have to be selected.

- **Return to origing.** Do you want the telescope to return to the original position after each dither pattern? This should be set to T if you want to perform the same dither pattern with more than one filter inside the same OB. Otherwise, the dither pattern of the 2nd filter will start at the last dither position of the first filter.

- **Filter.** For the first science template of the OBi it should be the same one used in the acquisition template, this minimizes overheads.

- **Sub-exposure time.** How long do you want each exposure to be?

- **Number of sub-exposures.** How many exposures do you want in the dither sequence? This number can be one if you want a single exposure. If you define your own dither sequence, this number can be equal, larger, or smaller than the number of steps in the sequence. If the number is larger than the number of offsets these will be cycled through.

- **CCD binning mode.**

- **Observation type.** Choose from the list to reflect the purpose of the observation.

These templates support three basic observing strategies:

5.3.1.1 Auto-dither patterns

To remove charged-particle events and detector blemishes, at least three offset images must be combined. A minimum of 5 dithered exposures are required to cover all gaps (the width of the vertical gaps between the CCDs is $\sim$24″, while the width of the horizontal gaps is $\sim$14″) *and* be able to deal with charged-particle events and detector blemishes. Note that the more frames that go into a final image, the greater the *total* read-out noise.

Furthermore, stacking and median-filtering of a set of dithered images may often be the only way to obtain a useful fringe map for near-IR observations.

Any RA offset made at a non-zero DEC will result in a translation *and* rotation of stars in the WFI field (this rotation can be corrected with a de-rotator, though the WFI rotator is unsuitable for this purpose). This effect is not a feature of the WFI *per se*, it is just that this effect is more noticeable in the WFI's large field. The extent of the rotation increases at extreme DECs (This is easily visualized by imagining a globe and a small cardboard square. As the square is moved around the equator, there is no rotation between overlapping squares. If the square is moved around a circle of extreme latitude, then there is rotation between the overlapping squares). On account of the WFI's large field of view, offsets in RA can introduce rotations between the frames which make it impossible to stack and vertically co-add the images by applying integer pixel offsets. Of course, images can be de-rotated using software, but this will not only degrade the PSF, but it will also spread the effect of bad columns to their neighboring columns. The southernmost declination for which one can hope to cover the gaps and still keep the rotation under control is $\sim$-70°, which is good enough for Magellanic Clouds observations.

Another reason to obtain a set of at least three dithered exposures is the correction of the photometric zero-points: to do photometry with an accuracy better than 5% it is necessary to determine a *photometric flat-field* combining at least three exposures with offsets in RA and Dec with an amplitude of at least 100″. Such large offset amplitude might be in conflict with the need to keep the rotation to a minimum, thus the actual dither pattern depends on the purpose of the observations.

If you wish to combine your mosaiced images by shift-and-add operations only, you should set `Auto-dithering` to `True`. The thereby selected fixed offsetting patterns are detailed in Table 5.3. If auto-dithering is specified, the offset pattern is automatically selected as a function of |DEC|, i.e. the sign of the declination does not matter. As discussed above, for the range $0° \leq |\mathrm{DEC}| \leq$—70°, these dithering patterns reduce the effect of field rotation to a level that will allow the resultant frames to be combined without de-rotation by software. South of -70°similar strategies are impossible. Nevertheless, the values in Table 5.3 provides a standard dithering patterns also for such southern positions.

By observing the first 5 positions given in Table 5.3, you will have at least three observations at each point. For the dithering sequences given in Table 5.3, 6 positions are required to have at least three observations at each point, whereas the full set of 7 positions will give 4 observations at each point.

If you wish to observe a field more times than there are offsets given in the appropriate table, you should copy the OB but execute it with a slight offset in delta (e.g. +/– 15″). We strongly suggest that the same dither sequence is not executed twice in an OB because a long OB is less likely to be scheduled (as of writing, the maximum acceptable execution time of any OB is 1 hour). The user should use the Initial Offset Value fields of the OB to apply this initial offset. The auto-dither will work in the standard manner after applying this initial offset. **But notice, that this offset is not included in the return-to-origin computation.**

All fixed dither patterns consist of 7 offsets. Note that if more exposures than offsets are specified, the dithering pattern repeats from the start. All offsets are *relative to the respective previous exposure*, not to some fixed reference position. Therefore, cycling through a dither pattern does *not* mean cycling through a number of positions in the sky because, except for specifically designed user patterns, the last position is *not* identical to the first one.

The dithering templates ask whether a 'combined offset' should be made. A 'combined offset' consists of switching off the autoguider, offsetting the telescope, offsetting the guide-box on the tracker CCD by the same amount, and then switching on the autoguider. The net result of these operations is to maintain the same guide star, despite the telescope having been offset. If you wish to use the autoguider for the acquisition of the images in the dithering sequence (highly recommended for exposure times greater than 60 sec), then this option must be set.

5.3.1.2 User-defined dither patterns

The same rules, etc. apply as for the fixed dither patterns except that users can define their own offsetting pattern. The maximum single offset is 9999″. But it should be noted that if the dither is set with the combined offsets flag to `T`, then the maximum allowed amplitude is much smaller and it depends on the relative location of the chosen guide star. The size of the *tracker* chip used for guiding is approximately 480″ in RA and 970″ in dec. For a guide star located at the center of the chip the maximum amplitude is then half the above values (and because of vignetting it could be less depending on the filter used and the brightness of

Table 5.3: Auto-dithering patterns (offsets in ″)

$0 \leq \|\delta\| \leq 30$				
Seq.	From Last		From First	
num.	$\Delta\alpha$	$\Delta\delta$	$\Delta\alpha$	$\Delta\delta$
1	...	...	0	0
2	+32	+24	+32	+24
3	–64	+24	–32	+48
4	–32	–72	–64	–24
5	+128	–24	+64	–48
6	–80	–24	–16	–72
7	+64	+144	+48	+72
$30 < \|\delta\| \leq 45$				
Seq.	From Last		From First	
num.	$\Delta\alpha$	$\Delta\delta$	$\Delta\alpha$	$\Delta\delta$
1	...	...	0	0
2	+32	+24	+32	+24
3	–64	+24	–32	+48
4	–16	–72	–48	–24
5	+96	–24	+48	–48
6	–64	+120	–16	+72
7	+32	–144	+16	–72
$45 < \|\delta\| < 60$				
Seq.	From Last		From First	
num.	$\Delta\alpha$	$\Delta\delta$	$\Delta\alpha$	$\Delta\delta$
1	...	...	0	0
2	+32	+24	+32	+24
3	–64	–48	–32	–24
4	+36	–24	+4	–48
5	–8	+96	–4	+48
6	+40	+24	+36	+72
7	–72	–144	–36	–72
$60 < \|\delta\| < 90$				
Seq.	From Last		From First	
num.	$\Delta\alpha$	$\Delta\delta$	$\Delta\alpha$	$\Delta\delta$
1	...	...	0	0
2	+26	+24	+26	+24
3	–52	–48	–26	–24
4	+30	–24	+4	–48
5	–8	+96	–4	+48
6	+16	+24	+12	+72
7	–24	–144	–12	–72

the stars available to guide, a particularly difficult problem for the U filter near the galactic poles – see the WFI Manual). If larger amplitude offsets are needed then set the combined offset flag to F: this will result in a less efficient observing procedure because the TIO will need to reacquire a new guide star for each new dither position. Note that offsets larger than 999 arcsec are done with a full telescope preset.

Important: The first offset in each pattern is executed right after the preset and before the first exposure. If this is unwanted, set the first offsets to zero in both RA and DEC. In any event, for n exposures n offsets need to be specified unless the dither pattern is to be resumed from the beginning.

This mode is particularly suited for projects not affected by the gaps between the unit CCDs but requiring a fairly uniform exposure over as large a fraction of each unit CCD as possible. The offsets should, then, be set to very few arcsec. In this case, a minimum of 3 exposures is required in order to permit particle events and detector blemishes to be removed. If the gaps between the CCDs are also to be covered, a minimum of 5 exposures is needed, and the offsets must be chosen such that every sky element is imaged on a CCD in at least three sub-exposures.

5.3.1.3 Stare

This is a special case of a user-defined dither pattern. Only one offset equal to zero in both RA and DEC needs to be specified, i.e. all exposures will be of the same field without offsets. Programs, that do not require coverage of the gaps between the CCDs but demand rigorous rejection of all data points compromised by bad pixels and a maximum number of equally observed sky elements would consider this mode. If at least 3 exposures are made, particle events can be corrected for whereas detector blemishes will always remain visible.

5.4 Calibration templates

Calibration templates are available for sky and dome flat fields, bias and dark exposures, and focusing. Because they do not normally require a particular set of sky coordinates, they are to be embedded in CalOBs. By contrast, calibrations by means of observations of celestial standard sources need to be executed as OBs.

All calibration data are made publicly available through the ESO Science Archive and are not subject to a proprietary period.

Important for Service Mode users: ESO routinely generates calibration data according to the WFI Calibration Plan (Doc. No. LSO-ESO-22401-00001; also check URL: `http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/CalPlan/StdCal/` for the latest details). The scope of this plan is to calibrate the instrument rather than specific data sets. The data are thought to be sufficient for most standard applications. Since ESO does not currently maintain a data reduction pipeline for WFI data, no quantitative statement can be made about the resulting accuracy. **It is the responsibility of the respective users to assess the adequacy of the strategy of the Calibration Plan for their specific purposes. Note also that the execution of the Calibration Plan is limited to the U, B, V, R, and I bands only.**

Users may request additional calibrations. However nighttime calibrations will be charged to their time account; daytime calibrations, excluding twilight flat fields, are limited to 10% of the night time allocation.

ESO will normally schedule the execution of calibration observations in the night of the corresponding science observations. However, especially if the science fields are spread over a large range in right ascension, their observations are likely to be spread over a correspondingly large range in time. If only one OB or CalOB of a given type of calibration observations is submitted, the mentioned proximity in time of its execution w.r.t. the associated science observations can be achieved only for some of the science OBs because *every OB or CalOB is executed only once*. If users judge this to be insufficient for the scientific aims of their projects, it is their responsibility to submit a corresponding number of calibration OBs *even if they are identical*.

5.4.1 WFI_cal_Darks

Label	Default	Values	WFI mode
Sub-exposure time (sec)	0	$0 \leq \Re \leq 3600$	img, spec
Number of sub-exposures	1	$1 \leq \jmath \leq 20$	img, spec
CCD binning mode	1x1	1x1, 2x2, 3x3	img
	1x1	1x1, 2x2, 3x3, 1x2, 1x3	spec

This Template acquires SEQ.NEXPO bias or dark exposures. Bias frames are acquired if the exposure time DET.WIN1.UIT1 is set to zero. Conversely, dark frames are acquired if the exposure time is non-zero (but above 0.1 sec). Typically one needs about 10 biases per night, while darks are not necessary fore most applications. Darks and biases are generally taken in the afternoon, or left running after a night of observations, with a dark dome, and the mirror cover closed (see Sec. 6).

The Sequencer Script will move the opaque filter (which is a piece of cardboard) into the beam. Note that if the exposure time is set to zero, then the shutter remains closed, for *non-zero* exposure times the shutter is opened.

This template should normally be embedded in a CalOB (so that no attempt is made to preset the telescope). The template can also be used in an Observation Block, but we strongly advise against this.

Because bias and dark exposures do not depend on the instrument mode, only one common template is offered for both imaging and spectroscopy: Do *not* choose binning factors 1x2 or 1x3 for imaging programmes, because they are not supported by the imaging-specific templates.

NB: This template is unique in that it accepts exposure times shorter than 0.1 sec. Exposure times with $0.0\,\mathrm{sec} < t_{\mathrm{exp}} \leq 0.1\,\mathrm{sec}$ should not be used because they are physically impossible. Unfortunately, P2PP does not permit this range to be blocked out: It is the responsibility of the user to respect this constraint.

5.4.2 `WFI_img_cal_DomeFlat` and `WFI_spec_cal_DomeFlat`

Label	Default	Values	WFI mode
Filter	NODEFAULT	Many	img, spec
Requested exposure level (ADU)	20000	$1000 \leq \jmath \leq 50000$	img, spec
Number of exposures	3	$1 \leq \jmath \leq 20$	img, spec
CCD binning mode	1x1	1x1, 2x2, 3x3	img
	1x1	1x1, 2x2, 3x3, 1x2, 1x3	img
Grism	R50	R50	spec
Rotator angle (degrees)	0	-10, 0, 10	spec

This calibration template acquires SEQ.NEXPO dome flat fields with an exposure level of approximately DET.EXPLEVEL ADUs through filter INS.FILT1.NAME. The Sequencer Script presets the telescope and dome to the appropriate positions. As no acquisition or target is needed, this sequence has to be embedded in a CalOB.

The exposure time is automatically computed as follows:

- A single CCD flat with exposure time 1 sec is acquired.
- The mean overscan value is subtracted from the flat and the mean net intensity is computed.
- From this net intensity the exposure time needed to reach DET.EXPLEVEL is calculated.

If the computed exposure time is less than 0.5 sec or greater than 400 s, the template will be automatically aborted. Adjustment of the voltage (by the operator) will almost always permit an exposure within this range to be used. Where this is exceptionally not possible, service mode users will be provided with data matching the requested exposure level as closely as possible.

The template delivers images which have a mean exposure level near the center of the mosaic within $\pm 5\%$ of that requested.

In the spectroscopy template, also the grism and the position angle of the Cassegrain instrument rotator as well as some additional CCD binning patterns can be specified.

5.4.3 `WFI_img_cal_SkyFlat` and `WFI_spec_cal_SkyFlat`

Label	Default	Values	WFI mode
Filter	NODEFAULT	Many	img, spec
Requested exposure level (ADU)	20000	$1000 \leq \jmath \leq 50000$	img, spec
Number of sub-exposures	3	$1 \leq \jmath \leq 20$	img, spec
CCD binning mode	1x1	1x1, 2x2, 3x3	img
	1x1	1x1, 2x2, 3x3, 1x2, 1x3	spec
Grism	R50	R50	spec
Rotator angle (degrees)	0	-10, 0, 10	spec

When taking into consideration sky brightness, filter, and CCD efficiencies, the order of less to more efficient filter is UVIBR. Thus, for evening flats start with the U and end with the R, and reverse the order for the morning twilight.

To avoid large drifts in the counts, the number of frames per SkyFlat OB should be no larger than three. If this is the case it is realistic to obtain, per twilight, 2 narrow band filters, the U filter, and three filters of the VIBR set. Thus, in a good night a total of 6 filters can be totally calibrated, with six exposures per filter. We repeat, LIMIT THE NUMBER OF FRAMES PER SKY FLAT OB TO 3.

These calibration templates acquire SEQ.NEXPO sky (twilight) flats with an exposure level of approximately DET.EXPLEVEL ADUs (on CCD #51) through filter INS.FILT1.NAME. Before each exposure the telescope is offset by 20″ in RA and 20″ in Dec such that the flats can later be median filtered to remove any stars (the telescope tracks during the SEQ.NEXPO exposures). The exposure time is computed automatically as follows:

- A flat field with a 2-second exposure time is acquired with CCD #51.
- The mean overscan value is subtracted from the flat and the mean exposure level is computed.

If several templates are combined into one OB or CalOB (recommended only in Visitor Mode – see below), this is repeated at the beginning of each template. If a template foresees multiple exposures, the exposure times for all subsequent integrations are automatically computed using the formula given by [20].

The sequence is started only if the exposure time of the first frame is greater than 0.5 seconds and less than 400 seconds. The sequence terminates when SEQ.NEXPO frames have been acquired or the exposure time exceeds 400 seconds or becomes shorter than 0.5 seconds. The template delivers images which have a mean exposure level near the center of the mosaic within $\pm 15\%$ of that requested (this value depends on the filter used).

The practical execution of sky flat field exposures depends strongly on the observing mode:

Service Mode: These templates *must* be used in a CalOB. The TIO will preset the telescope to the default hour angle and declination (–30° and 1 hour into the east for dusk flats, and 1 hour into the west for dawn flats). It is also his responsibility to optimize the order in which the filters are used. **For this reason, each sky flat field CalOB must contain only one `WFI_img_cal_SkyFlat` or `WFI_spec_cal_SkyFlat` template.** There is, therefore, also no need to distinguish between dusk and dawn flats.

Visitor Mode: The templates may be used in either an OB or a CalOB. If used in an OB, then it is the responsibility of the observer to ensure that the target package is correct (obviously, to point at a given hour angle means that the RA needs to be adjusted according to the local sidereal time). If the template is used in a CalOB, then the TIO will preset the telescope to the default locations (–30° and 1 hour into the east for dusk flats, and 1 hour into the west for dawn flats) before executing the CalOB.

Because the spectroscopic mode does not use slits, sky flats make sense also in this mode. In the spectroscopy template, also the grism and the position angle of the Cassegrain instrument rotator as well as some additional CCD binning patterns can be specified.

5.4.4 `WFI_cal_FocusSeq`

Label	Default	Values	WFI mode
Filter	NODEFAULT	Many	`img, spec`
Sub-exposure time (sec)	15	$10 \leq \Re \leq 60$	`img, spec`
Number of sub-exposures	9	$1 \leq \jmath \leq 15$	`img, spec`
Telescope focus offset (eu)	40	$5 \leq \jmath \leq 100$	`img, spec`
Temperature compensation?	T	T, F	`img, spec`

Not strictly a science exposure, but certainly something you need to know about. It takes 10 to 15 minutes to complete a focus exposure. The telescope is automatically focused with a formula that works well within 30 degrees of the zenith. To optimize image quality for other positions it becomes necessary to focus.

In Service Mode, it is not possible to request focus exposures; it is the responsibility of the TIO to ensure that the telescope is well focused. In Visitor Mode, observers can request that a focus exposure be made.

This calibration template acquires a *through focus* frame. It takes SEQ.NEXPO sub-exposures with exposure time DET.WIN1.UIT1 seconds through filter INS.FILT1.NAME. If SEQ.NEXPO is EVEN, then SEQ.NEXPO+1 exposures are taken. In between the sub-exposures, the shutter is closed and the charges are shifted on the CCD by 50 pixels. Readout only takes place after all sub-exposures have been made.

At the end of the exposure, a MIDAS batch (different for imaging and spectroscopy mode) is used to analyze the resulting image, and a best focus value determined (a graphical plot is made as a sanity check). First the TIO is prompted to click on one of the stars. Then, the focus curve is presented as a MIDAS graph. The best focus value calculated using that star is presented in an editable field. The TIO is then prompted to either: (1) accept proposed focus, apply offset and exit; (2) modify the focus in the editable field, apply offset and exit; (3) measure again a star and repeat process; or (4) do nothing and quit.

A special Boolean flag (if set to `TRUE`) permits temperature variations, which at the beginning of a night may be significant even during the execution time of the focusing procedure, to be compensated by corresponding movements of M2.

The focus sequence template is normally embedded in a CalOB, and consequently has no target associated with it. The TIO will examine the OBs which will be executed following the focus sequence, and decide on a good telescope position at which to make the focus exposure. For example, if all subsequent OBs were LMC observations, then a focus would be made in an uncrowded field close to the LMC. Conversely, if the subsequent OBs contained targets all over the sky then a focus would be made close to zenith.

5.5 Naming Conventions for Images Produced by the Templates

All the templates produce one or more images (with the exceptions of `WFI_img_acq_Preset` and `WFI_spec_acq_Preset`) which are stored in `$INS_ROOT/SYSTEM/DETDATA` on the instrument workstation, `w2p2ins`. Three different naming conventions are used for the `FITS` files as they propagate through the ESO Data Flow System:

1. Upon their first creation, file names are built according to the scheme `<imagename>.<number>.fits` where the values of `<imagename>` are the ones provided in Table 5.1 and `<number>` is a separate running index for each category of `<imagename>`. An example is WFI_Ima.3.fits.

2. Within the domain of the Science Archive, files are named `WFI.<timestamp>.fits` where `<timestamp>` encodes the time of creation of the original file in the format YYYY-MM-DDThh:mm:ss.sss. An example is WFI.2001-02-11.T17:51:34.374.fits.

3. The naming scheme is also maintained for files delivered by the Science Archive in Garching to the users. However, the original file names (as described under 1 above)

are contained in the primary `FITS` keyword `ORIGFILE` of their headers and can be restored from there.

Warning: Every time the disk of the WFI instrument workstation is cleaned, the counter `<number>` is reset so that files with different contents may have identical original file names.

Eventually, the templates will automatically update a log file, which will contain, for each image, the name of the image itself, its identifier, start MJD, exposure time, filter, and grism used. This file is not intended as a full observing log book, but serves as an easy (and automatic) way to keep track of what has been done during a night. Visitor Mode users can request a copy from their TIO. Service Mode users will receive it together with their data from the Science Archive.

5.6 Checklists

A necessary requirement for the syntactic integrity of OBs is their not being rejected by the P2PP-intrinsic verification tool. However, for a scientifically successful observing program, there are additional essential requirements and considerations, which are compiled in the following two subsections.

Important: At present, there are no tools for the testing by users of OBs according to these criteria. If upon submission of Service Mode OBs the User Support Group finds any such problems, users will normally be requested to rectify them. However, there are many reasons, which would permit imperfect OBs, especially in the case of complex programs, to propagate to the telescope. Therefore, the responsibility for the respecting of the above rules is the user's. In Service Mode, ESO executes OBs as submitted.

5.6.1 WFI templates checklist for visitor mode

- Read the description of the telescope and instrument (Chapter 2).
- Use the Exposure Time Calculator to define exposure times and optimize the choice of filters.
- Finalize the list of target fields (with coordinates and, if applicable, differential tracking rates).
- Use the Digital Sky Survey or similar sources to check for bright stars in or close to your fields.
- Define your dithering strategy (if any).
- Determine your calibration needs.
- Read the general P2PP manual.
- Read the WFI Templates Tutorial (Sect. 5.8).
- Upon arrival on La Silla, contact your Support Astronomer (use the paging system and Nos. 02, or 12).
- Start P2PP and define your OBs and CalOBs keeping in mind the following:

- Before defining OBs containing more than one non-acquisition template, carefully think about alternatives.
- Keep the execution time of any OB as short as is compatible with your scientific objectives.
- All offsets in the science templates are relative to the respective last position. The first offset is performed before the first exposure.
- If fewer offsets are specified than exposures, the offset list is cycled through again. This does not mean that observations at previous positions are repeated!
- A guide star is required for moving targets.
- Never combine imaging and spectroscopic templates in one OB or CalOB.
- Do not combine calibration templates with science templates in one OB. (Remember that observations of scientific calibration sources in the sky have to be defined as science OBs.)
- CalOBs should only be used for biases, darks, dome flat fields, twilight flat fields and focus sequences.
- OBs have to be used for all other calibrations, including astrometric, photometric, and spectrophotometric standards.
- Do not include more than one filter in Sky flat templates, as described in Sect. 5.4.3.
- Sort your sky flat OBs in the order suggested in Sect. 5.4.3.
- Do not include more than one filter in templates with auto guiding on.
- Bias exposures should only for very specific reasons be included with OBs.
- A rotator angle can only be defined in spectroscopic acquisition templates. Because each OB contains only one acquisition template, observations at different rotator angles require separate OBs.
- Try to give your OBs meaningful mnemonic names. Memorize them.
- Rather than defining OBs/CalOBs for each and every exposure off line, it can be more efficient to create only a few generic ones and edit parameters such as filter, exposure time, coordinates, etc. on line.

Beware that the `Verify` function of P2PP does not recognize most of the above! Nevertheless: Do use it for every OB/CalOB you define.

5.6.2 WFI templates checklist for service mode

- Read the description of the telescope and instrument (Chapter 2).
- Use the Exposure Time Calculator to define exposure times and optimize the choice of filters.
- Finalize the list of target fields (with coordinates and, if applicable, differential tracking rates).
- Use the Digital Sky Survey or similar sources to check for bright stars in or close to your fields.

- If a bright star is to be centered on a gap between the mosaic CCDs, prepare a finding chart compliant with the specifications in the general Phase 2 Proposal Preparation information provided by ESO.
- Define your dithering strategy (if any).
- Determine your calibration needs. Examine the WFI Calibration Plan.
- Determine the operational overheads (look the latest info at the La Silla SciOps web page)..
- Read the general P2PP manual.
- Read the WFI Templates Tutorial (Sect. 5.8).
- Start P2PP and define your OBs and CalOBs keeping in mind the following:
  - Make maximum use of the possibility to insert comments in the fields provided for this purpose in the P2PP GUI.
  - The full constraint set must be edited for each OB.
  - Limit constraints to what is critical for the success of the project. Otherwise, the probability of your OBs being schedulable and, therefore, executed may drop drastically.
  - Remember that no assumptions can be made about the order and times in and at which your observations are carried out, unless specific constraints are set. (But all observations defined in one OB are executed in one go and in the order of the templates contained therein.)
  - For the same reason, **never** set the `New Preset` flag in WFI acquisition templates to `False`!
  - Depending on the category assigned to your project by the Observing Programmes Committee, you can neither assume that all OBs of your project will be executed. Assigning priorities to OBs can, therefore, be a good idea.
  - Every OB is executed only once (important for calibrations).
  - Every OB is executed exactly as submitted. ESO will not apply any modifications.
  - Before defining OBs containing more than one non-acquisition template, carefully think about alternatives.
  - Keep the execution time of any OB as short as is compatible with your scientific objectives. If a total execution time (incl. overheads) of more than one hour is strictly unavoidable, contact `usd-help@eso.org` about a waiver.
  - All offsets in the science templates are relative to the respective last position.
  - If fewer offsets are specified than exposures, the offset list is cycled through again. This does not mean that observations at previous positions are repeated!
  - A guide star is required is required for moving targets.
  - Never combine imaging and spectroscopic templates in one OB or CalOB.
  - Do not combine calibration templates with science templates in one OB. (Remember that observations of scientific calibration sources in the sky have to be defined as science OBs.)

- CalOBs should only be used for biases, darks, dome flat fields, and twilight flat fields.
- OBs have to be used for all other calibrations, including astrometric, photometric, and spectrophotometric standards.
- Focus templates cannot be submitted in Service Mode.
- CalOBs for sky flat fields must not contain more than one filter as the service observer needs to plan the order in which different filter OBs will be executed. OBs must not at all be used for sky flats.
- Bias exposures should only for very specific reasons be included with OBs.
- A rotator angle can only be defined in spectroscopic acquisition templates. Because each OB contains only one acquisition template, observations at different rotator angles require separate OBs.

Beware that the `Verify` function of P2PP does not recognize most of the above! Nevertheless: Do use it for every OB/CalOB you define.

- Compare the grand total of the execution time (incl. overheads) of all OBs to the time allocated to your project.
- Submit your OBs/CalOBs (and any finding charts).

5.7 Selecting constraint sets for service mode

A very important aspect of the writing of templates for service mode observations is the selection of adequate constraints. If they are too strict, the observations will not get done. If they are too loose, the observations might be useless. The following is meant as a guide summarizing some of what we have learnt in the last few years.

Seeing and airmass: These two constraints should be discussed together because of the strong dependence of seeing with airmass, but perhaps more importantly, because of atmospheric dispersion, which shows an even stronger dependence with airmass for blue, broad-band filters. The seeing grows like the 0.6-th power of the airmass, and like the 0.2-th power of colour. This means for WFI that going from the Z filter to the U filter we should expect a 15% degradation in seeing due to the colour dependence of the seeing. Going from airmass 1 to airmass 2 increases the seeing by 50%. But we can see from Table 2.7 that for the U filter, going from airmass 1.15 to 1.5, the stellar elongation in the direction of the parallactic angle increases by a factor of 2, from 0.62″to 1.23″! When the service mode observer measures the seeing, s/he does in a direction orthogonal to the parallactic angle, reporting the smallest of the two values from the "Pick object" command of the RTD. We can see here another good reason not to mix filters such as the B/123 and I/203, as the constraints of the I/203 will be the ones respected by the service mode observer. We can recommend that users do not set this constraint stronger than the following values for the broad-band filters: 1.2″for U; 1.0″for B; 0.8″for V,R, and I.

Transparency: The transparency constraints can be PHO, CLR, THN, and THK, for photometric, clear, variable thin and variable thick cloud cover. As discussed in Sec. 6.1.2, the constraint PHO implies that observations taken at different times, and positions during the night can be compared. While CLR implies that during the execution of an OB, there were no clouds in the direction of the target. PHO nights are much more scarce than CLR moments during the night. Thus, it is a good idea to subdivide the OBs into a small subset of PHO types, and the bulk of the integration time with OBs with the transparency constraint set to CLR. This increases the chances of an OB to be observed.

FLI and moon distance: Any observations with filters redder than R should probably request twice the integration time with a FLI of 0.5 or worst. This also will increase the chances of an OB being executed. The user should be careful not to set at the same time a large FLI and the transparency constraint set to THN, as this could result in an extremely high background. Regrettably, there is no way to link the different constraint so as to allow things such as:
FLI=0.5 .and. Transp=CLR .or. FLI=0.0 .and. Transp=THN.

5.8 Tutorial for P2PP 2.9 for WFI

P2PP (v2.9) is a program for building the lists of instructions that direct the telescope and instrument during an observing run. These "lists of instructions" are called **Observing Blocks** (OBs), and control many aspects of an observing run, including telescope movement, filter placement, exposure time, dithering pattern on the sky, and more. The goal with OBs is to make the observing process as automatic, and therefore repeatable, much as possible.

A related entity is the **Calibration Block**. These are instructions for the telescope and instrument to take calibration frames (e.g. bias frames). They are similar to Observation Blocks in many respects, but for *one important difference*. Calibration Blocks do not specify the coordinates of an object on the sky, meaning that the telescope cannot be pointed to a sky position using one.

P2PP, V2.9, is the tool to be used starting P75, and has as new added features the possibility of attaching finding charts and README files. These features should be used when preparing Observation Blocks for service mode programs. For the actual preparation of OBs only the latest version of P2PP should be used.

In this guide we will go through an example of creating and editing OBs for an observing run with the 2.2 m/WFI. The creation of Calibration Blocks is so similar that we will not discuss them further.

5.8.1 Getting started

If you carry out this tutorial at your home institution you should install P2PP following the instructions at the ESO web site. At La Silla the user should be able to run P2PP in the user room with one of the Linux machines.

To start type `p2pp &` and wait. P2PP usually takes a minute or so to get going.

A dialog box will come up, asking for a User ID and password. Use the ID number you were assigned. The program will contact a center in Garching to check that these are valid, and if so, the main P2PP session will commence.

5.8.2 Making an observing block

5.8.2.1 Creating the block

The main P2PP window (cf. Figure 5.1) shows some folders down the left-hand side and a list of OBs in the center. What folders are there depends on what ESO observing programmes you are authorized to create/edit OBs for, (through the ID number and password you are using). For the `51020` number there is a fictitious observing programme with ID: 60.A-9120(A), for the 2.2 m/WFI.[1] The only limitation here is that only WFI OBs can be created, since only one telescope/instrument combination is allowed per sub-proposal.

[1] The reason for this system is so that astronomers can only create/edit OBs for programmes on which they are the main observer. As such, each visiting astronomer will have his/her own ID number and password which they will have obtained beforehand from User Support Group (USG) in Garching. In this tutorial we are using the ID reserved for the WFI calibration plan. The observer should not prepare his/her OBs with this ID.

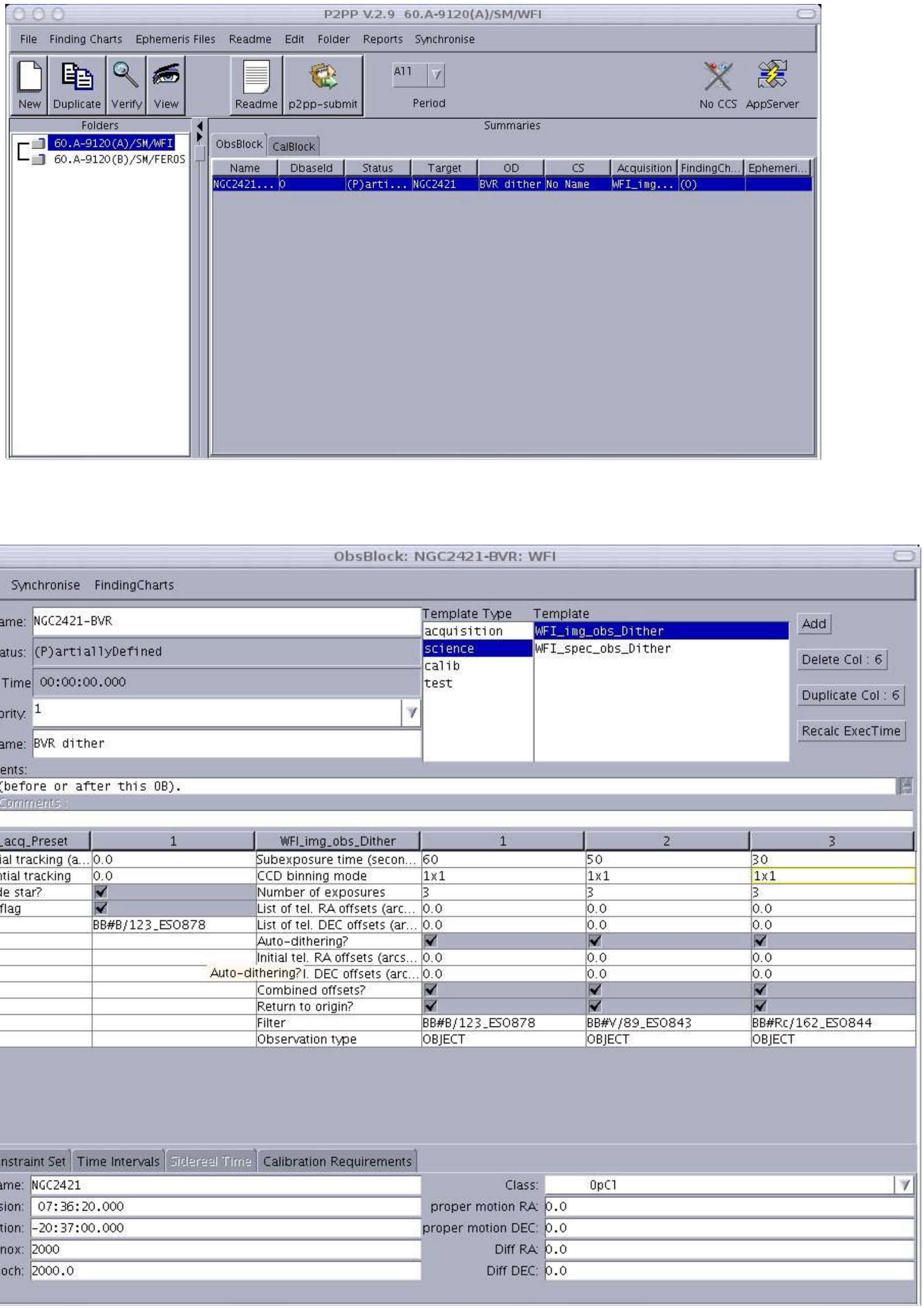

Figure 5.1: P2PP V2.9 main window.

To create an OB for this "programme":

1. In Folders, select 60.A-9120(A)/SM/WFI, (which should be automatically selected if it is the only one).

2. Select the ObsBlock in the Summaries area. This tells the system that you want to create a new OB, as opposed to a Calibration Block.

3. Click on New. This will open up a new (empty) OB in the Summaries area. The fields will become filled-in with details once the OB has been fully-created.

4. Select the View icon and the area for entering/editing the details of this OB will appear, in a new window.

Suppose we want to observe a star cluster NGC 2421, in each of B, V and R for 60, 50 and 30 seconds respectively. We first need to give the OB a name. In the top left-hand corner of this new window enter the Name as `N2421 - BVR`. Leave the User Priority field with its default value (`1`) and enter the OD Name as `BVR dither`. The User Priority field says what relative priority an observer gives this OB in his or her programme. The OD Name is a short Observation Description,describing the content of the OB.

Now we need to tell the telescope where to point. This information goes at the *bottom* of the OB window as follows:

1. Enter the Object Name as `NGC 2421`, RA as `07:36:20` and Dec as `-20:37:00`. In this case the default Equinox and Epoch values are correct and so remain unchanged.

2. It is also possible to add the details of the Proper Motion of an object in this panel, although for NGC 2421, this information is not relevant. Differential tracking (if needed), is also entered into this panel. Leave these at the default values for now.

3. Set the object Class to `OpCl`. This field is meant to classify the OB according to the type of object being observed.

4. Comments about the target can be added in the User Comments box. It is a very good idea to use these comments boxes. Add a comment to the User Comments box.

5.8.2.2 Acquiring the target: the *acquisition template*

Entering the coordinates as we have done above is *not* enough to move the telescope to those coordinates. To do this, we need to put an **Acquisition Template** into the OB, which does exactly that. Note that Calibration Blocks do not allow the inclusion of Acquisition Templates, which is their main difference from OBs.

So what are "templates" in relation to "observation blocks"? **Templates** are the individual building blocks that go together to form an OB. There is one (and only one) Acquisition Template and one or more **Science Templates** per OB. We will get to Science Templates below.

The templates are listed in the top right-hand corner of the OB window. To view the full names you have to widen the OB window to the full width of the screen.

To create the Acquisition Template:

1. Select the Template Type to `acquisition`. Doing so brings up a list of all of the possible acquisition templates that have been specially-written for the 2.2 m and WFI. From this list, choose the `WFI_img_acq_Preset` template and click on Add. This brings up a grid of input values associated with this template in the center of the OB window.

2. Enter differential tracking rates of `0.03` for RA and `-0.05` for Dec. Select the B filter from the Filter table. The New Preset flag can stay `True`.

3. Of course, since we are observing a star cluster, the differential tracking rates should actually be *zero*. Edit the differential tracking boxes to change these values back to 0.

The Acquisition Template is done.

5.8.2.3 Observing the target: the *science template*

Now that we have told the telescope to go, we can tell it what to do when it gets there. We do this through the first **Science Template**:

1. In the top right-hand corner, change the Template Type to `science`, and choose the `WFI_img_obs_Dither` template (click on Add). See how this template is added alongside the first in the center of the window.

2. Select B from the list of Filters and enter `60` seconds of Individual exp. time. Set the Number of exposures to `21` and the Observation type to `OBJECT`. Leave the other entries unchanged.

3. Notice that if the number of template entries is longer than the space provided in the OB window, you will have to scroll up and down using the scroll-bar on the right-hand side. Alternatively, you can enlarge the OB window vertically.

4. Notice that there are options for Return to Origin? and Combined Offset?. Return to Origin? asks whether or not you want the telescope to return to its initial position once the dithering sequence is complete. Combined Offset? asks whether the guide star is to be taken into account when making the offsets for dithering, so that guiding can be maintained. **If the acquire guide star flag is set to `F` in the acquisition templates then the combined offsets flag have to be set to `F` in the observation templates or the OB will not work at the telescope.**

5. We have finished entering all of the entries for the `WFI_img_obs_Dither` template. But notice that Number of exposures is highlighted in *red*. This is because the value (`21`), is out of range. If you point the cursor to this field (*without* clicking on it) a pop-up message will show the allowed range. Re-enter a value of 3. Now the template is ready.

We have a Science Template for the B-band observations, but none yet for the V or R. Add the V observations as a new `WFI_img_obs_Dither` template, selected from the top right-hand corner using Add, as we did before. Enter the correct filter and Exposure time (`50` seconds). The Observation Type is again `OBJECT` and the Number of Exposures 3.

We need to do one more Science Template for the R exposures, which is another `WFI_img_obs_Dither` As you might have guessed, there's a quicker way to create new templates from existing ones when they are similar. With the yellow field cursor in column 2 (the V template), click on the Duplicate button up top. A third Science Template (column 3) will be created alongside the V template.

Edit this third template to include the R filter and an exposure time of 30 seconds. All other entries are the same as V template.

We have almost finished with the OB. Notice in the central section of the OB window we have four folders: Constraint Set, Time Intervals, User Comments, and Calibration Requirements. These are used for setting the requirements of Service Mode observations, and the conditions under which they can be observed. Since our observations of NGC 2421 are for Visitor Mode, we leave the default values in.

5.8.2.4 Closing the finished observing block

Now that the OB is complete, select File and Close from the pull-down menus along the top. The OB window will close and you will be returned to the main P2PP window. To confirm that there are no errors in the OB, click on the Verify button. If all is well, you will be told so.

Note that because P2PP saves your OB details as you go, *no separate saving operation is needed.* This is both a blessing and a curse: if P2PP crashes in the middle of a session[2], you can recover with your most recent version. However, if you make a mistake while editing, there is *no way to retrieve your previous version.* Be warned.

5.8.2.5 More templates: the *calibration template*

We have created an Acquisition Template to point the telescope at NGC 2421 and three Science Templates to take seven dithered exposures in each of BVR. But what about some calibrations?

1. Select the CalBlock in the *Summaries* area.

2. Click the New icon to create a new OB, and then click on the View icon to start editing.

3. Select `calib` from the list of possible template types in the top of the OB window. Select the `WFI_cal_Darks` template. Next, click the Add box at the upper right hand corner. Edit the number of exposures to 10. Edit the name to Evening BIAS, and the OD Name change it to BIAS. After this select Close from the File menu.

Next, repeat the previous procedure but to create a set of dome flats in the B, V, and R filters..

[2] Not completely outside the realms of possibility...

5.8.3 Creating a new observing block from another

5.8.3.1 Same target through different filters

Suppose now we want to create another OB for NGC 2421, but using different filters. The additional filters through which we want to observe the cluster are Hα and [OIII]/2. As you probably guessed, there is a short-cut which makes creation of the new OB quick and easy.

1. In the main P2PP window click the ObsBlock in the Summaries area. The previous OB will be highlighted, since it is currently the only one. In the Edit pull-down menu click on Duplicate and an identical copy will be created and placed *above* the old one. It will be the new one that is now highlighted.

2. Click on the View button to open an OB window on the new copy. Notice that the *only* difference between the copy and the original is that the Name has an `-0` extension appended.

3. Edit the Name to `N2421 - narrowband` and the OD Name to `narrowband dither`.

4. Since we only require observations through *two* filters in this OB, Delete the Science Template in column 3 (for R-band).

5. In the first Science Template, change the Filter to Hα and the Individual exp time to `100` seconds. *R*emember to change the filter in the acquisition template to be the same as that of the first Science Template so that the OB does not become unnecessarily inefficient.

6. Change the second template entries to [OIII]/2 and 200 seconds.

7. The OB is now done. Close the OB window and Verify the OB.

See now in the main P2PP window that the new OB details have been updated, and that either OB can be viewed by first highlighting with the cursor, and then selecting View.

5.8.3.2 Same filters on a different target

We now have two OBs, both observations of NGC 2421: one through two narrowband filters (Hα and [OIII]/2), the other through three broadbands (BVR). Suppose now we want to *repeat* those same sets of observations, but on a *different* object: Trumpler 35, another open star cluster.

Again we have a short-cut to their creation:

1. First duplicate the `N2421 - BVR` OB as we did in the previous section. Then view it. At the top, edit the OB Name to `T 35 - BVR`. At the bottom, change the target Name to `Trumpler 35` and enter the different RA as `18:43:00` and Declination as `-04:08:00`. Everything else about the OB remains the same. Leave the OB window open but return to the main P2PP window.

2. We need to create the Trumpler 35 narrowband OB using the *target* information of one but the *template* information of another. In the main P2PP window, duplicate the `N2421 - narrowband` OB.

3. We need to transfer the target information from the `T 35 - BVR` OB. Highlight this one in the main P2PP window. Select Synchronize and then Copy Target from the pull-down menus. This action copies the target information from the `T 35 - BVR` OB to memory.

4. Now highlight the new `N2421 - narrowband-0` OB. This time, select Synchronize and then Paste to Selected OBs. Doing so transfers the Trumpler 35 target information from memory to the `N2421 - narrowband-0` OB. P2PP will prompt you about whether you want to perform the action: answer `yes`. You will see the information in the Target column update.

5. In the OB View Window, edit the Name from `N2421 - narrowband-0` to `T 35 - narrowband`. The new OB is complete.

Close down the OB window and return to the main P2PP window. We should create the DomeFlat CalOBs for these filters also but we will skip that step in this tutorial.

5.8.4 Finding and correcting errors

The four OBs we have created seem to be without errors. To check whether an OB has any errors, highlight it and click on the [Verify] button. Everything should be reported as OK. Note that an OB may well not work at the telescope, even if P2PP reports that it is correct. The P2PP software is not yet clever enough to detect all possible errors in an OB.

Let's insert an error into one of the OBs and see whether P2PP can find it:

1. View the `T 35 - narrowband` OB and change the Number of exposures in the Hα template from `3` to `21`. Notice that the number is now *red*: something is wrong. Pointing the mouse at the field (but *not* clicking) will show the reason: the number of exposures needs to lie between 1 and 20. Leave it at `21` and return to the main P2PP window.

2. Notice that the `T 35 - narrowband` OB has a *red dot* next to the name. This is what signifies something is wrong with this OB in the main window.

3. Highlight the OB and click on [Verify]. P2PP should report the error and where it lies.

4. Return to the OB View Window and change the `21` to a `3`. Close the OB window and return to the main P2PP window. The red dot should now have gone. The OB is OK once more.

5.8.5 Generating reports

Now that we have complete set of OBs we can generate various text reports about the observations, and save these to file or print hard-copies.

Suppose we want a breakdown of the exposure and execution time of the programme, for all objects:

1. First we need to sort the OBs in the Summaries window so that OBs for the same target are grouped together. Click on the Target button at the top of the column and the OBs will be sorted thus.

2. Select Reports from the pull-down menus, and then Execution Time and All. A new window will appear with the OB Execution Time Report:

```
OB Execution Time Report
------------------------

  Programme Id        Id OB Name                          Exptime    Exectime
  60.A-9120(A)           N2421-BVR                         00:07:00   00:11:10
  60.A-9120(A)           N2421-narrowband                  00:15:00   00:19:10
  60.A-9120(A)           T35-BVR-0                         00:07:00   00:11:10
  60.A-9120(A)           T35-narrowband-0                  00:15:00   00:19:10
  Totals                                                 OT00:44:00 OT01:00:40
```

Note that a single OB should not take longer than **1 hour** (also keep in mind that in service mode the four OBs above could be executed in four separate nights!)

As a second example, suppose we want to get a summary of just the *narrowband* observations:

1. First we need to sort the OBs according to the OD (Observation Description). Clicking on the OD button should do this.

2. To highlight the two narrowband OBs at the same time, first highlight the top one. Then hold down the SHIFT key and position the cursor on the second one. Both OBs should now be highlighted. Non-adjacent OBs can be selected by clicking while holding the Ctrl key simultaneously (you can also try Shift-Control click).

3. Select Reports and ObsBlocks Breakdown and Selected from the pull-down menus. A summary of just the narrowband observations should be given:

```
OBSERVATION BLOCK BREAKDOWN
===========================


N2421-narrowband  60.A-9120(A)/SM/WFI

Target    : NGC 2421, RA:  07:36:20.000, Dec: -20:37:00.000, Eq: J2000

ObsDesc: narrowband dither

WFI_img_acq_Preset:
New preset flag        T                    Acquire guide star?    T
RA differential trac.. 0                    DEC differential tra.. 0
Filter                 NB#Halpha/7_ESO856

WFI_img_obs_Dither:
Auto-dithering?        T                    List of tel. RA offs.. 0.0
List of tel. DEC off.. 0.0                  Combined offsets?      T
Return to origin?      T                    Filter                 NB#Halpha/7_ESO856
Sub-exposure time (se.. 100                  Number of sub-exposures 3
CCD binning mode       1x1                  Observation type       OBJECT


WFI_img_obs_Dither:
Auto-dithering?        T                    List of tel. RA offs.. 0.0
List of tel. DEC off.. 0.0                  Combined offsets?      T
Return to origin?      T                    Filter                 NB#OIII/2
```

```
Sub-exposure time (se.. 200                  Number of sub-exposures 3
CCD binning mode       1x1                  Observation type       OBJECT


ConSet: No Name
Seeing                         : 2.0
Sky transparency               : Photometric
Air mass                       : 5.0
Fractional lunar illumination : 1.0
Moon angular distance          : 30

============================
T35-narrowband-0  60.A-9120(A)/SM/WFI

Target    : Trumpler 35, RA:  18:43:00.000, Dec: -04:08:00.000, Eq: J2000

ObsDesc: narrowband dither

WFI_img_acq_Preset:
New preset flag        T                    Acquire guide star?    T
RA differential trac.. 0                    DEC differential tra.. 0
Filter                 NB#Halpha/7_ESO856

WFI_img_obs_Dither:
Auto-dithering?        T                    List of tel. RA offs.. 0.0
List of tel. DEC off.. 0.0                  Combined offsets?      T
Return to origin?      T                    Filter                 NB#Halpha/7_ESO856
Sub-exposure time (se.. 100                  Number of sub-exposures 3
CCD binning mode       1x1                  Observation type       OBJECT


WFI_img_obs_Dither:
Auto-dithering?        T                    List of tel. RA offs.. 0.0
List of tel. DEC off.. 0.0                  Combined offsets?      T
Return to origin?      T                    Filter                 NB#OIII/2
Sub-exposure time (se.. 200                  Number of sub-exposures 3
CCD binning mode       1x1                  Observation type       OBJECT


ConSet: No Name
Seeing                         : 2.0
Sky transparency               : Photometric
Air mass                       : 5.0
Fractional lunar illumination : 1.0
Moon angular distance          : 30

============================
```

Both of these reports can be saved to file or printed out.

5.8.6 Exporting the OBs

To transport the OBs to the mountain it is necessary to export the OBs. For this you should follow these simple steps:

1. Create a folder under the impex directory of your p2pp installation with an appropriate name.
2. From P2PP select the OBs that you want to export.
3. Select the export option of the File menu.
4. Navigate to the directory where you want to place the exported OBs, select it (do not double click on it, just a single click so that it is outlined), and then click on the Select Export Directory button. The OBs will be exported to that directory as extension .obx files.
5.

5.8.7 Checking-in OBs into the ESO repository

This procedure might change, please check with with the latest P2PP manual and with USG for the latest procedures. After checking that:

1. None of the OBs contain errors and pass the verification step,
2. no OB has an execution time longer than an hour,
3. all OBs have appropriate constraints sets,
4. all OBs have appropriate comments,
5. all OBs have finding charts attached,
6. all OBs have README files attached,
7. the total execution time does not exceed the allocated service mode time,

the user is ready to check-in the OBs into ESO's OB repository: just select the OBs that will be checked-in and select the Check-in option in the File pull-down menu. A lock icon should appear to the left of each OB name, and the DbaseId should change from 0 to the value assigned by ESO to that OB. That particular OB can not be edited anymore unless it is Checked-out of the ESO OB repository.

5.8.8 Finishing P2PP

In the main P2PP window, select File and then Quit. The session will end and all files are automatically saved.

Chapter 6

WFI calibration plan

A calibration plan is used by the SciOp staff for monitoring and calibrating WFI data. The plan we have adopted has two components: *Standard calibration* and *Instrument calibration.*

6.1 Standard calibration

The WFI Standard Calibration Plan encompasses the use of the following *standard* filters

- BB#U/50_ESO877 (previously named U/360)
- BB#B/123_ESO878 (previously named B/NEW)
- BB#V/89_ESO843
- BB#Rc/162_ESO844
- BB#I/203_ESO879 (previously named I/EIS)

Notice that if you use the old U/38, the old B/99, or any other filter that you want photometrically calibrated it is mandatory that you also submit calibration OBs for those filters (dome flats, sky flats, and standard star observations). Although we keep an eye over which filters have been used during the night, and try to obtain dome and sky flats for them, it is the responsibility of the PIs to supply the necessary OBs.

Table 6.1 shows the standard calibration plan in a nutshell.

There are 2 components to the Standard Calibration plan: Instrumental Calibration (InstCal), and Photometric Calibration (PhotCal).

6.1.1 InstCal: instrumental calibration

The InstCal is comprised of the following observations:

- 10 biases
- 5 dome flats in each standard filter
- 5 twilight flats in each standard filter

Table 6.1: Standard calibration plan in a nutshell

Component	Exposure time/ background level	Scope	Notes
Bias frames	0 s each frame	Ten each day following a service mode night	Taken irrespective of whether Standard Calibrations were done the night before
Dome flats	∼20,000 ADU	Five for each filter used the previous night	Taken with the flat field lamp, adjusting its voltage depending on the filter (to avoid saturation or too short an exposure)
Sky flats	∼20,000 ADU	At least three per filter used the previous night (provided weather conditions permit)	In extreme cases it may not be possible to obtain this many sky flats for each filter in a single night. The demands of non-standard calibrations will have a bearing on this and will similarly vary form night to night. The team will do its best to obtain at least two sets of 3 sky flats within two nights of a given science OB
Landolt fields	60 s and 120 s per field for U; 10 s and 30 s per field for BVRI	Two exposures per field; 3-4 fields per night, of which two might be obtained during twilights	The Landolt fields are chosen from the following list: SA92, SA95, SA98, RU149, TPhe, SA101, SA104, SA107, SA110, SA113; neither dithering nor guide stars are used; minimum airmass is 1.2 for all fields except TPhe (almost 1.0), and the maximum is ∼1.8; only a few stars occupy each CCD in the mosaic.

If your program uses standard filters, the InstCal will be performed automatically (i.e. there is no need to request it in the Phase II service mode README file.)

If your program contains filters other than these, you must create your own OBs for skyflats and dome flats. You can only request a maximum of 3 flats/OB. Biases will automatically be taken. If these specific OBs are not included, no calibration OBs in these filters will be undertaken by SciOps. These calibration OBs are not part of the Standard Calibration Plan but are executed where necessary. Repeat calibrations (on different days) must be specified individually, unless prior arrangements have been made with ESO's USG and La Silla SciOp.

6.1.2 PhotCal: photometric calibration

As part of the Photometric Calibration plan the following observations are made:

- 3-4 Landolt standard star fields taken at different airmasses every night classified as PHO.

PhotCal will be executed only under the following conditions: the night is PHO, and your OB transparency constraint is set to PHO. It is sometimes difficult to decide whether a night is truly photometric, thus, for practical purposes we classify a night as PHO when no clouds are visible during twilights and during the night. During such a night we observe OBs with PHO constraint, together with standard stars. OBs with a transparency constraint set to CLR are observed during any night in which there is no clouds in the direction of the target. The difference between the PHO and CLR constraint is as follow: PHO means that the observations of the science target and the standard fields can be compared; that is, the atmosphere has to have similar characteristics during the different times at which the observations are made, and at the different sky positions the observations are made; PHO implies CLR over the whole sky and over at least the whole night. OBs with a transparency constraint set to CLR or worst will not necessarily have associated Landolt field observations.

If your program uses standard filters, the PhotCal will be performed automatically every PHO night. If your program contains filters other than these, you must create your own calibration OBs for standard fields, and indicate clearly in your README file how you would like these OBs executed.

6.1.3 Execution sequence

The execution sequence of the Calibration Plan is similar to what follow (some details might change, such a the order in which different airmass fields are observed):

- **Evening twilight.** Sky flats in the standard filter set for that night. These can be replaced, augmented with non-standard sets for programs in the queue.
- **Evening twilight (later).** Telescope pointing accuracy verification. This is the first OB executed after the sky flats, and just before the Standard stars observations.
- **Late evening twilight.** the Landolt field closest to the meridian, in only the filters chosen for the night. This first field can be observed in a larger number of filters, some of which might be dropped, together with their respective programs, as the night progresses (due to changing conditions).

- **Three or four hours after Sunset.** a Landolt field at higher airmass than the first one observed.
- **Three or four hours before Sunrise.** the Landolt field now closer to the meridian.
- **Pre-dawn.** a Landolt field at a higher airmass than the previous one.
- **Morning twilight (optional).** sky flats in the filters chosen for that particular night, only if suitable sky flats were not obtained during the evening twilights.

6.2 Instrument calibration

The instrument calibration plan aims solely to provide data to quantify instrument behaviour for the information of La Silla SciOp staff. It is not designed to supply calibrations for use in the reduction of science data. That being said, these instrument calibration data are available to users through links on the WFI webpage. The analysis of instrument calibration data is undertaken mostly by the La Silla SciOp staff.

Instrument calibration data are grouped in terms of short, medium, and long-term calibrations.

6.2.1 Short term calibrations

6.2.1.1 Daily health checks

Determines the read-noise, gain, bias, and flat-field levels. These are plotted as a function of time, and the graphs are displayed on the web. The link can be found at

`http://www.ls.eso.org/lasilla/sciops/2p2/CCDs/WFI`

6.2.1.2 Weekly healthcheck

Determines bias level, β light response gain, shutter error, CCD transfer function, linearity error, gain, and RON, on a chip-by-chip basis. The data and plots are kept at

`http://www.ls.eso.org/lasilla/sciops/2p2/CCDs/WFI`

6.2.1.3 Image quality monitoring

Roughly every 2 hours during the night, the TIO measures the image quality and reports the image FWHM in x and y, together with wind speed, wind direction, and other environmental data. The data is then plotted in the web, with links at

`http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/CalPlan/plotiq.html`

6.2.1.4 Photometric zero point monitoring

The standard star observations taken as part of the Standard Calibration plan are analyzed in real time with `tmag` to return a zero point of the instrument in each filter. No atmospheric extinction is determined but a reference atmosphere is used to reduce the data.

6.2.2 Medium term calibrations

These are calibrations that are done either quarterly or every six months. At present we do not have the resources to reduce the data, but we make sure that the archive is populated with the necessary frames.

6.2.2.1 Bad pixel mask determinations

Observations of the flat field screen are obtained with two different light intensities. The pixels that deviate form a linear relationship are flagged as bad. Further details and the masks can be found at

`http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/CalPlan/BADPIX/`

6.2.2.2 Absolute photometric zero points in UBVRI

At least twice a year, a full photometric solution for the WFI mosaic is obtained using the `tmag` package. The latest solutions can be found at:

`http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/zeropoints/`

6.2.2.3 Astrometric solution

Every 6-months. Remains to be implemented.

6.2.2.4 Sky concentration in UBVRI

Every 6 months. Although correction masks have been determined, an easily applied procedure remains to be implemented. Our current map can be found at

`http://www.ls.eso.org/lasilla/sciops/2p2/E2p2M/WFI/zeropoints/zpmap`

6.2.3 Long term calibrations

6.2.3.1 Telescope pointing model

The pointing model of the telescope is analyzed using the standard tpoint software. The latest solution is shown in Figure 6.1, with an rms of $6''$.

6.2.3.2 Focus change with temperature and other variables

Yearly check. A model of the change in focus with temperature and other variables is being continuously improved as this has the potential to impact positively on image quality and the efficiency of observations.

6.2.3.3 Filter focus offsets

Yearly check and refinement. The database containing the filter focus offsets with respect to the fiduciary B/99 filter is checked at least once per year.

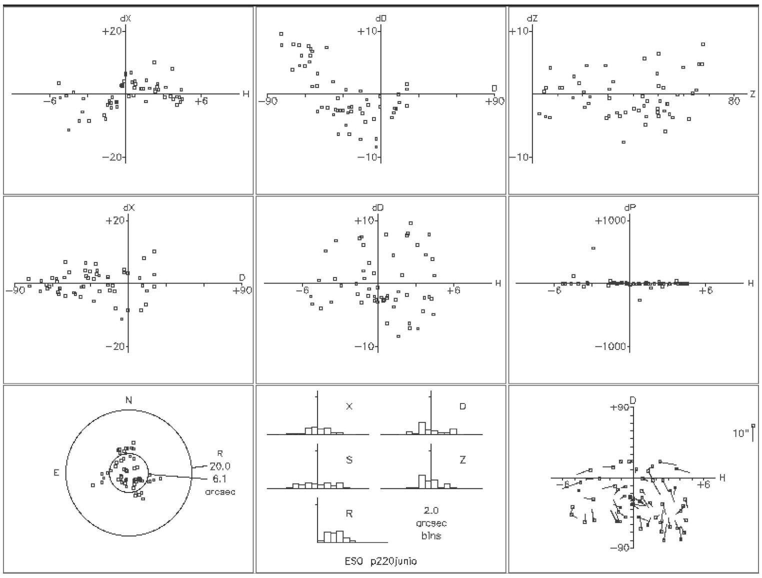

Figure 6.1: The pointing model of the MPG/ESO 2.2-m telescope in June 2001.

6.2.3.4 Tilt of the mosaic

The relative position of the CCD planes relative to the focal plane was measured during commissioning. We keep track of the image quality, and this test will be repeated if problems are encountered.

6.2.3.5 Filter image quality

At the moment of commissioning of a new filter, and 3-yearly thereafter.

Chapter 7

Reducing WFI data

This section is a quick schematic presentation of the reduction of WFI data. It uses the package ECLIPSE [7], as a reference reduction package. ECLIPSE is a lightweight software package ideally suited for the quick pre-processing of astronomical data (it requires the qfits library [8] for the handling of FITS files directly). It is not a complete image reduction and analysis environment such as MIDAS or IRAF. Nevertheless, what it does, it does it efficiently and well.

We have taken the eclipse-wfi package, and modified it to work directly with the Multi-Extension FITS files which are the delivered data products of WFI. This version of the package, that we have renamed `mef` and it is supported by one of the authors of this document, consists of the single C program `mefpp` with the following switches:

mefpp -bpm: This creates bad pixel masks for a list of WFI frames. It flags as bad all pixels with a value of 65,535 or larger. The mask thus created is multiplied by the instrument specific bad pixel mask.

mefpp -astrometric: This corrects the WFI astrometric keywords, by fixing the CRVAli, and CRPIXi keywords of each extension headers.

mefpp -overscan: This subtracts the overscan values, line by line, and then trims the data to the on-sky pixels only.

`mefpp -linearity:` This yet to be implemented functionality does a linearity correction for a list of WFI frames. It is here as a reminder that to go below 1% accuracy in all chips this is a must.

`mefpp -illumination:` This yet to be implemented functionality does an illumination correction for a list of WFI frames. It is here as a reminder that to go below 10% accuracy (sic) in all chips this is a must.

mefpp -cal: This calculates the master flat field, given as input a list of dark frames, a list of dome flat fields, and a list of twilight sky frames.

mefpp: This is the program that should be run after the master flat, and master bias frames have been determined. It goes over each image of a list of science frames, correct the astrometric keywords, and applies overscan and bias subtraction, trimming, and flat field division. It output a single BITPIX=-32 MEF file for each input BITPIX=16 MEF file.

What is in bold-face in the above description should appear nearly simultaneously with this document. The other are still research in progress. This is mostly a TBC document, and it is incorporated at this stage just to enumerate the basic processing steps required to reduce a set of WFI observations, thus, giving potential users a framework for the preparation of their observations.

7.1 Inspection of delivered data products

The reduction of WFI data starts with the inspection of the delivered data, and the proper partitioning of the data set. By partitioning we mean the subdivision not only into different filter sets, but also the determination of which flat-fields and biases are going to be used for which science frames. We recommend the use of the ECLIPSE tools `dfits` and `fitsort`.

`dfits` is simply a tool that lists the headers of a FITS file, while `fitsort` is used to select FITS keywords and to produce a table-like listing of their values. `dfits` work with MEF files. For example, the command

```
dfits /data/raw/2004-05-11/WFI_.fits | fitsort arcfile obs.targ.name exptime ins.filt1.name tel.airm.start | grep Landolt
```

produces the following listing

```
ARCFILE                            OBS.TARG.NAME   EXPTIME   INS.FILT1.NAME    TEL.AIRM.START
WFI.2005-02-12T05:16:12.797.fits   Landolt-SA101    9.9175   BB#B/99_ESO842    1.142
WFI.2005-02-12T05:17:49.525.fits   Landolt-SA101   29.9176   BB#B/99_ESO842    1.143
WFI.2005-02-12T05:21:05.628.fits   Landolt-SA101    9.9168   BB#B/123_ESO878   1.143
WFI.2005-02-12T05:23:37.173.fits   Landolt-SA101   29.9174   BB#B/123_ESO878   1.144
WFI.2005-02-12T05:27:00.530.fits   Landolt-SA101    9.9174   BB#I/203_ESO879   1.145
WFI.2005-02-12T05:29:11.326.fits   Landolt-SA101   29.9167   BB#I/203_ESO879   1.146
```

of all the Landolt standards observed during the night of 2005-02-11. A first column, giving the file names of the form /data/raw/2005-02-11/WFI_Ima.XX.fits, have been edited out for clarity from the above listing, leaving only the keyword values. The program `dfits` understands the abbreviated form of ESO's hierarchical keywords, form in which the keyword "HIERARCH ESO OBS TARG NAME" is written as OBS.TARG.NAME.

7.2 Creation of BPM for instrument and frames [mefpp -bpm]

Each science frame should have an associated bad pixel mask which flags the bad pixels. These can be the result of bad columns, or pixels, and are thus flagged by an instrument bad-pixel mask, or they can be the result of saturated pixels in the science frame itself. The flagging of saturated pixels has to be done at this stage, in which the data is still untouched, and in integer form. The value of data that need to be flagged as saturated is exactly 65,535. It is not necessary to loose data by flagging smaller values as saturated, as the linearity of the CCDs is better than 1 %, for all the range of the AD-converter, and for all chips but one. Only chip #55 has poorer linearity behaviour, at the ± 1.5 %, but these is rather small compared with many other effects. In any case, the linearity (and the shutter timing errors) have been shown to be quite stable over the course of the years, and it should be possible to correct for their effects for all pixel values smaller than 65,535. We are working to produce a routine to do that.

7.3 Astrometric keyword correction [mefpp -astrometric]

This program is not quite what its name implies, at least not yet. It modifies each extension header of the WFI frames so that CRVALi, and CRPIXi are self-consistent, and consistent with the RA and DEC keywords of the primary headers. The CRVALi keywords should be the coordinates of the center of rotation of the WFI adapter, close to the center pixel of the MOSAIC. Because the center pixel of the mosaic is blind we use the pixel (4150,3950) as pointing reference. This pixel has the advantage of being close to the center of the mosaic, but sufficiently far from the gaps such as for most pointings a target star will not fall in any of the neighboring gaps.

Currently, the frames which are delivered as data products has CRVALi keywords with the value one. This points to the southeastern-most pixel of the mosaic. This programs changes the value of CRVAL1 to 4150, and CRVAL2 to 3950, and corrects CRPIX1 and CRPIX2 accordingly. This gives positional accuracy equal to that of the pointing model, that is $\pm 10''$ rms. In a future version, the program should then query the USNO catalogue for a list of stars to refine the solution, which should permit an improvement of the astrometry to $\pm 0\farcs25$.

7.4 Overscan and bias subtraction, and trimming [mefpp -overscan]

The next step of the data reduction consists in the subtraction of the over (and/or pre) scans from the data. In the case of WFI there is a dependence of the overscan/prescan levels on the line number, it is thus necessary to do the subtraction in a line-by-line manner (bright stars also increase the overscan levels). At the same time we can specify a master bias frame to be subtracted after the subtraction of the overscan (this bias frame is also overscan subtracted). The subtraction of this bias frame is necessary to reduce the almost unnoticeable *ringing* of the bias level affecting the first few on-sky pixels which are read. At the end, if the user so chooses, the frames can be trimmed to get rid of the overscan pixels.

7.5 Linearity correction [`mefpp -linearity`]

The linearity of all but one of the CCDs of the WFI mosaic is better than $\pm 1.0\%$, peak-to-valley. The non-linearity of chip #55 is $\pm 1.5\%$. Thus, if we intend to do photometry to better than 1% accuracy over the whole mosaic it becomes necessary to do a linearity correction. The required linearity data is kept in the La Silla WFI web pages. Notice that the web page data folds the effects of CCD non-linearity, and shutter error, thus it is not directly applicable to science data. It needs to be first corrected by the shutter error. The actual effect of the correction on real science data has not been tested yet. This functionality is not offered yet.

7.6 Illumination correction [`mefpp -illumination`]

The correction of the data by an illumination correction can be done in the frame themselves or at the catalogue level, once aperture photometry has been performed. To reduce the systematic variations of the zero points of the photometry within the field below 10% peak-to-valley it is necessary to obtain large amplitude dithered observations of a standard field in at least three frames, displaced in orthogonal directions. This functionality is not offered yet.

7.7 Master flat field and bias frames creation [mefpp -cal]

`mefpp -cal` is used to create the master bias and flat-field frames. It is called as follow:

```
mefpp -cal [-bias blist] [-dome dlist] [-sky slist] or
meffpp -cal
```

where blist is a file containing a list of the WFI_Dark.*fits frames to be used to create a master bias frame; dlist is an analogous listing of WFI_FlatDomeIma.*fits frames;and slist is a listing of of WFI_FlatSkyIma.*fits frames. The program processes the files extension by extension, leaving at the end a MEF file containing the master flat field file. If called with the `-cal` switch it assumes default values for the above parameters.

7.8 Preprocessing of WFI science frames [mefpp -prep]

Once the master bias and flat field frames have been created we process each image, extension by extension, using `mefpp -prep`. In this stage we create the BPM for each of the frames as the `and` operation between the instrument BPM and the saturated pixels mask, which is created by the `mefpp -prep` routine itself if it does not exist. The program checks the presence of the keyword BPM in the headers of each image. This keyword has the name of the bad pixel mask. The program then checks the existence of that frame; if the keyword is not present the program determines a BPM, save it to disk, and write the keyword with this name in the image headers. If the keyword exists, but the file it points to does not, the program issues an error message and skips to the next file to be processed.

At the end of this step every WFI frame has been overscan subtracted, bias-frame subtracted, flat-fielded, and trimmed. And each of the frames has an associated BPM. A very rough initial WCS solution has also been written into the headers (with an accuracy not better than $10''$rms).

Further processing will depend on the particular use of the data and will not be cover in this document.

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Chapter 8

Frequently asked questions

8.1 General OB preparation

8.1.1 The pointing of the telescope is centered at what pixel on the mosaic?

The pointing is currently centred such that your target object will fall on pixel (4150,3950). This is on the top right-hand side corner of chip 7. The telescope pointing has an rms accuracy of better than 10″.

8.1.2 Can I position a given star on a particular pixel in the mosaic?

Yes you can, using the **WFI_img_acq_MoveToGap**, or after Period 74, **WFI_img_acq_MoveToPixel** templates. You can figure out the x,y positions of the pixels using Figure 2.5. Remember, for service mode observations, that you need to clearly indicate the star you are talking about and give the coordinates where you want it. The way to do this is marking the star very clearly in the finding chart attached to the OB, and include in the finding chart the pixel coordinates desired for the star. This last step is not necessary if you use the MoveToPixel OB because the pixel coordinates are written to the OB itself. Starting with Period 74 the MoveToPixel is the preferred template.

8.1.3 Can I position a bright star in one of the inter-chip gaps?

Yes you can, using the **WFI_img_acq_MoveToGap** template. Remember, for Service Mode observations, you need to clearly indicate the star you are talking about. It will be moved to the closest gap (unless specified otherwise).

8.1.4 I want to make large offsets between exposures. Will that cause problems?

This really depends on how big your offsets are and the parameter **Combined Offsets**. If you choose **Combined Offsets = True**, the success of the combined offset depends on exactly where we have managed to find a guide star on the tracker chip, and exactly how big your offset is. We suggest you set **Combined Offsets = False** if you plan to do large offsets. This means we will have to choose a new guide star after each offset (overhead 1 minute each time), but this is much more efficient than if we have to abort and restart your OB again when the guiding fails.

8.1.5 How can I minimize my overheads when observing with WFI?

As you can see from the table of overheads for WFI , by far the biggest overhead that can be avoided is that involved in changing filters. Therefore, the easiest way to minimize overheads is to minimize filter changes.

8.1.6 Can I make my OBs longer than one hour?

For Visitor mode observations you are free to make your OBs as long as you wish.

For Service mode observations, if you want to make your OBs longer than 1 hour, you *must* get a Phase II Waiver approved by the User Support Group in Garching first.

In practice, it is much better to keep your OBs as short as possible since the weather conditions at La Silla are not stable over long periods of time. In particular, the seeing can vary widely over the space of an hour, so if you require good seeing ($< 1.2''$), your OBs have a better chance of being executed fully within constraints if you keep your OBs short!

8.1.7 Is there a standard OB to do a sequence where a standard field is placed on each of the 8 chips?

There is one available for download from the WFI web page. This can be imported directly into P2PP and changed as required. If you wish to make your own OB from scratch, the offsets you need are of 510″ in RA. This will move the field to the equivalent position in the next chip. To move by half a field at constant RA the offset to be applied should be of 980″ in DEC.

8.2 Service mode preparation

8.2.1 What filters are included in the standard calibration plan?

Starting Period 71, the Standard Calibration Plan (Chapter 6) consists of the filters **U/50, B/123, V/89, Rc, I/203**

8.2.2 I have to submit calibration OBs for non-standard filters. Will I be charged time to execute these OBs?

For non-standard Skyflat and Domeflat calibrations, you will not be charged for time (provided you don't send us an excess of them to do!) For photometric and spectrophotometric standard fields (i.e. anything that must be executed during the night), you WILL be charged the time.

8.3 Properties of WFI

8.3.1 Is it possible to rotate WFI?

No. You must use WFI in its default orientation. Having said that, for GRISM work it is possible to rotate WFI $\pm 10°$.

8.3.2 I want to use a special filter which is not part of the ESO WFI filter set. How can I do this?

We do not normally mount special filters (or even filters from other ESO sets) in the ESO WFI. However, you may state your case and ask ls-imaging@eso.org whether it would be possible. If they agree, the filters must be provided to La Silla at least 2 months before the start of the observations.

8.3.3 What was the reason to upgrade the B/99, Ic/lwp, and U/38 filters? What is the improvement?

The intention was to reduce the colour terms by better matching the standard band-passes, and improving efficiency. In the case of U there was an improvement in both of these issues. For the B filter only the latter was accomplished.

8.3.4 Is there fringing in the R and I bands? Is it stable?

There is fringing in the Ic/Iwp and I/203 filters. A detailed report on the fringing patterns in these filters is available from the WFI website. So far we do not know how variable the pattern is. The intensity varies a lot, but the shape seems to be quite stable. We plan to do more measurements in the near future to clarify this point.

The R band does not show fringing except during periods of high solar activity.

8.3.5 Are the photometric zero points and colour terms of each chip known?

We do not have many opportunities to measure such things, however, an attempt was made during March 2004. The photometric solutions for each chip in each of the standard filters can be found from the WFI website.

8.3.6 How good is the astrometry solution in the FITS headers?

Currently there is no astrometric solution inserted in the headers. One can simply be inserted by correcting the CRVAL keywords which currently do not correspond to the center of rotation of the instrument. Doing so would give a WCS as accurate as the telescope pointing, $\sim 10''$. This solution can be refined using the USNO catalogue to $\sim \pm 0.25''$.

8.3.7 Is there a significant wavelength shift between the centre and edge of the mosaic when using the narrow-band filters?

TBD

8.4 WFI reduction

8.4.1 Is there a pipeline to reduce WFI data?

There are several pipelines floating around to reduce WFI data. Of those publicly available we can mention the EIS pipeline at ESO, to be found at the URL:

http://www.eso.org/science/eis/software/release_30000018_EIS-MVM.html

There are a few other packages that exist to reduce mosaic data. At the very least there is the **IRAF: mscred** package at URL:

http://iraf.noao.edu/

and the **Flips** reduction package at the CFHT, URL:

http://www.cfht.hawaii.edu/ jcc/Flips/flips.html

We are also providing a set of ECLIPSE based programs that work on the WFI MEF files, without the need to split them. Nevertheless, this set of C program are only meant (at this stage) to provide a reference framework for the discussion of WFI data reduction needs.

8.4.2 The long ESO headers are causing problems to reduce IRAF data. How can I fix this?

The FITS files produced by ESO instruments make extensive use of hierarchical keywords. While these are allowed by FITS, IRAF cannot deal with them. To convert these keywords (e.g. from HIERARCH ESO TEL AIRM START to AIRMASS) use the **hierarch28** program developed by N. Devillard. This program, together with a series of other useful FITS-related programs, is available at the ESO standalone fits tools webpage. These tools are part of the **ECLIPSE** package, and therefore directly available at the telescope and on any ESO machine.

Alternatively, you can download the **ESOWFI** package for IRAF to help you out.

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