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LA SILLA OBSERVATORY

SOFI

User's Manual

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Chapter 1

Introduction

SOFI or **S**on **OF I**SAAC is the infrared spectrograph and imaging camera on the NTT. In many ways, it resembles its "parent" ISAAC, and the EFOSCII on the 3.6m. Both are focal reducing instruments capable of imaging, spectroscopy and polarimetry.

SOFI offers the following observing modes.

- imaging with plate scales of 0.144, 0.144, 0.273 and 0.288 arc second per pixel in the following modes: Small Field, Large Field + Focal Elongator, Spectroscopic Field and Large Field, respectively; broad and narrow band filters in the wavelength range from 0.9 to 2.5 microns are available.
- low resolution R∼600 (varies across the wavelength range), 0.95-2.52 micron spectroscopy with fixed width slits of 0.6, 1 and 2 arc seconds, and slit length of 4.92 arcmin.
- medium resolution R∼1500 (varies across the wavelength range) H and K-band spectroscopy, with fixed width slits of 0.6, 1 and 2 arc seconds, and slit length of 4.92 arcmin.
- 0.9-2.5 micron imaging polarimetry with the large field objective (0.288 arcsec per pixel) and the set of filters available in imaging mode.

This manual is divided into several chapters. For proposal writers, it is sufficient to read chapter 2, giving a general description of the instrument. For those who will be observing at the telescope, it is sufficient to read up to the end of chapter 4. Chapter 3 discusses how to use observation templates to set up observations and chapter 4 describes how to use the instrument at the telescope. For those who will reduce data taken with SOFI, it is sufficient to read chapters 2, 3 and 5. Chapter 5 discusses how to reduce data taken with SOFI. At the end, there are appendixes which contain various information useful for observers (detailed template descriptions and examples, fits headers information, calibration data, etc.).

1.1 A First and Final Word

The authors of the manual hope that you find this document useful in writing SOFI proposals or for preparing for your SOFI run. The manual is continually evolving. Some sections still need to be written and some figures still need to be included. If you have any suggestions on how to improve the manual please contact the La Silla Science Operations department (lasilla@eso.org).

Nota Bene:

- The SOFI Template Signature Files (hereafter TSF) Parameters Reference Guide is suppressed by this manual (see Appendix C)!. Those of you who are successful in being awarded SOFI time must read this document and the related P2PP Users' Manual before coming to observe with SOFI.
- This document contains a data reduction cook book (Chapter 5) with detailed description of the individual data reduction steps. The users must read it carefully before preparing their observations because the good understanding of the data reduction will help you to plan the observations better and more efficiently.
- There is also a WEB page dedicated to SOFI. It is accessible from the SciOp home page: `http://www.ls.eso.org/lasilla/sciops/`
  There you will find the most up-to-date information about the instrument, recent news, efficiency measurements and other useful data that do not easily fit into this manual or a subject of frequent changes. This WEB page is updated regularly.

1.2 Applicable documents

1 VLT-MAN-ESO-14100-1510 OS Users' Manual

2 VLT-MAN-ESO-14100-1531 DCS Users' Manual

3 VLT-MAN-ESO-14100-1094 ICS Users' Manual

4 VLT-MAN-ESO-00000-000/1.1 P2PP Users' Manual

5 VLT-MAN-ESO-00000-000 SOFI TSF Parameters Reference Guide (obsolete)

1.3 Abbreviations and Acronyms

The abbreviations and acronyms used in this manual are described in Table 1.1.

Acronym	Description
BOB	Broker of Observing Blocks
DCR	Double Correlated Read
DCS	Detector Control System
DEC	Declination
DIT	Detector Integration Time
EMMI	ESO's Multi-Mode Instrument
ESO	European Southern Observatory
FWHM	Full Width at Half Maximum
ICS	Instrument Control System
IR	Infra-Red
ISAAC	IR Spectrograph And Array Camera
NDIT	Number of DITs
NDR	Non-Destructive Read
NINT	Number of NDITs
NTT	New Technology Telescope
OB	Observing Blocks
OS	Observing Software
P2PP	Phase 2 Proposal Preparation
PSF	Point Spread Function
RA	Right Ascension
RON	Read Out Noise
SOFI	Son Of ISAAC
TCS	Telescope Control System
TSF	Template Signature File
VLT	Very Large Telescope
ZP	Zero Point

Table 1.1: Abbreviations and Acronyms used in this manual.

Chapter 2

SOFI - Son of ISAAC

2.1 Optical Layout

SOFI is mounted on the Nasmyth A focus of the NTT. The light from the tertiary mirror of the telescope enters the front window which has no optical power. Immediately after the front window is a cryogenically cooled mask wheel which coincides with the telescope focus. The mask wheel contains several masks: one for each imaging objective, three for long slit spectroscopy, a pinhole mask and a special mask used with polarimetry.

The optical layout is shown in Figure 2.1.

The mask wheel is followed by a collimating lens (used to focus the instrument), two filter wheels, a grism wheel, an objective wheel, and then the detector itself. The re-imaged pupil of the telescope, the primary mirror, is located on a slightly undersized stop just before the grism wheel.

The first filter wheel contains the standard broad band near IR filters, several narrow band filters, two order sorting filters for low resolution spectroscopy, an open position and a fully closed position. The second filter wheel contains more narrow band filters, a focus pyramid, an open position and a fully closed position.

The grism wheel contains three grisms for long slit spectroscopy, a Wollaston prism for imaging polarimetry, an open position and a fully closed position.

The objective wheel contains two objectives for imaging at $0\farcs288$ (large field) and $0\farcs144$ (small field) per pixel, a spectroscopic objective, an open position and a fully closed position.

2.2 Imaging

SOFI offers imaging at several different pixel scales. The pixel scales and the fields of view are summarized in Table 2.1. The large and small field objectives are used with the corresponding mask in the mask wheel that covers the same field of view. The masks reduce the amount of stray light entering the instrument.

For a normal use of SOFI (rotator angle = 0 deg) the orientation is showed in the Figure 2.2. You could modify the orientation simply using a rotator angle in the template. This option could be useful in spectroscopy if you want to align two objects in the slit (the positive angle is from the north to the east) or in imaging if you want to map some asymmetric target, i.e. an elongated galaxy. A simple rule of thumb says: to align the North-South axis of the field of view (or the slit, in case of spectroscopy) along an axis on the sky with a certain Position Angle, one has to apply in the acquisition template a rotaton angle equal to this Position Angle.

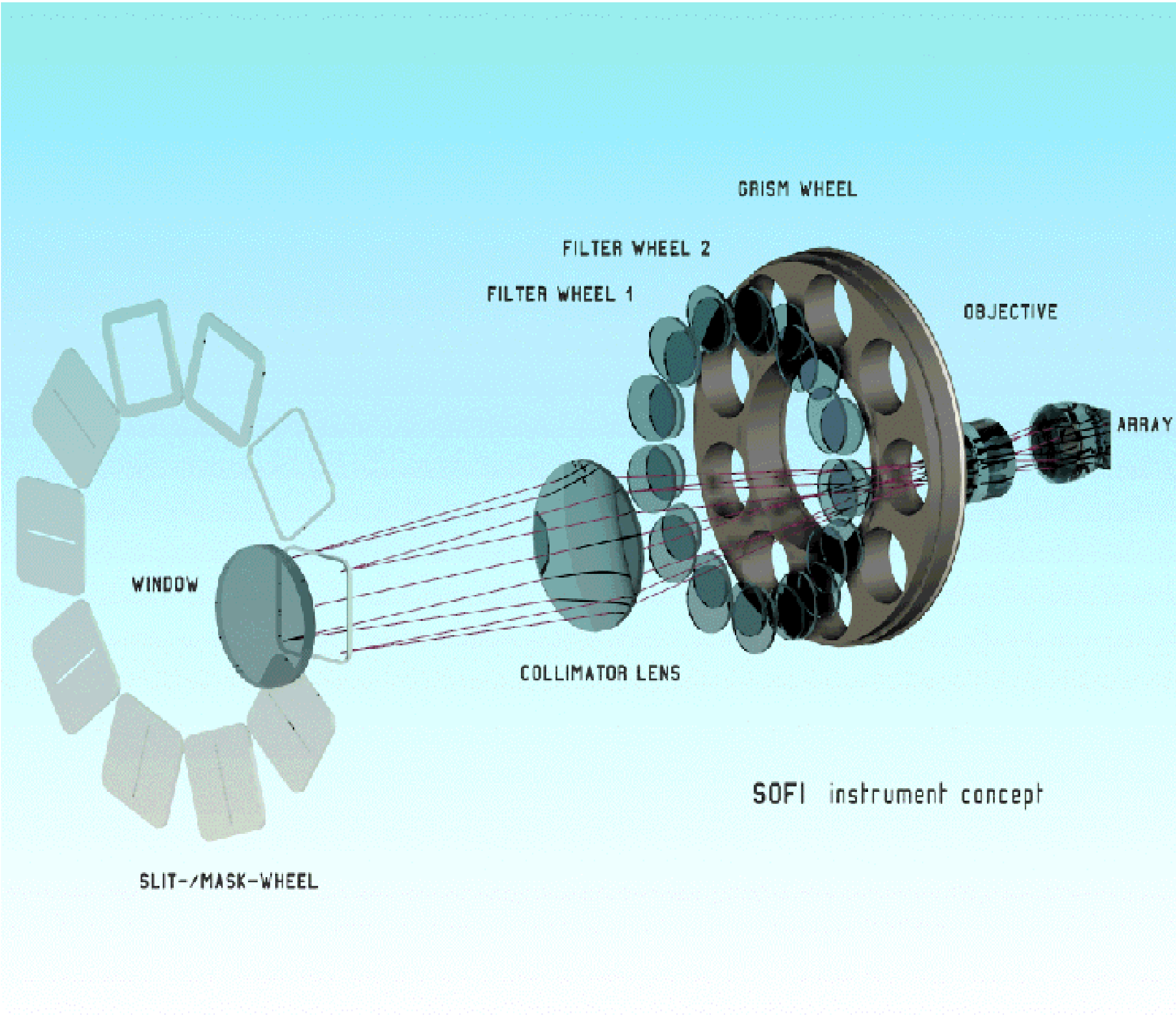

Figure 2.1: Optical layout of SOFI

Objective	Pixel Scale	Field of View
Large Field Objective	0.288	4.92' x 4.92'
Spectroscopic Objective	0.273	4.66' x 4.66'
Small Field Objective	0.144	2.46' x 2.46'
Large Field Objective + Focal Elongator	0.144	2.46' x 2.46'

Table 2.1: The fields of view and the pixel scales available with SOFI.

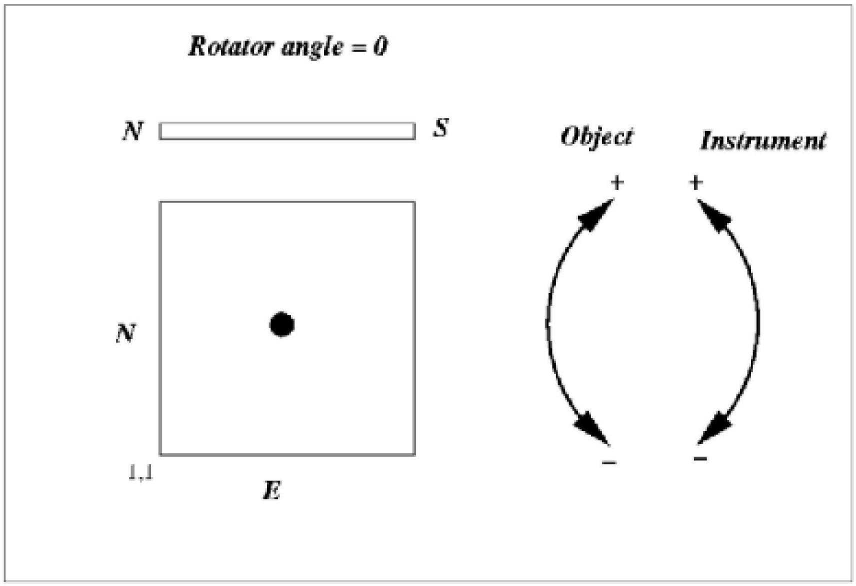

Figure 2.2: Orientation of SOFI for rotator angle 0 deg: In imaging the North is to the left and the East to the bottom of the image. The slit for the spectroscopy is oriented North-South. **Nota Bene:** To align the North-South axis of the field of view (or the slit in case of spectroscopy) long a certain Position Angle, one has to apply in the acquisition template a rotaton angle equal to this Position Angle.

The spectroscopic objective can be used to take images with a scale that is a bit finer than that of the large field objective; however, this objective is chromatic, as mentioned above. This means that the pixel scale is a function of wavelength. It also has an illumination pattern with a central light concentration.

All the aforementioned objectives suffer various amounts of image degradation over their respective fields of view. We routinely try to improve the image quality during interventions. Please consult the instrument web pages or the instrument scientists for the latest status of the instrument.

There is a focal elongator in the grism wheel which can be used in combination with the large field objective to image with a pixel scale that is identical to the pixel scale of the small field objective. The image quality is usually superior than that of the small field objective, but this mode is 10% to 15% less efficient because of the additional optical elements.

Imaging can be done through the standard IR broadband filters: J, J_s, H, K_s, a Z filter which peaks at 0.9 microns, and many narrow band filters. The filters, together with their central wavelengths and widths at half maximum, are listed in Table 2.2. Listed also are the cut-on wavelengths for the two order sorting filters. These filters are used with the two low resolution grisms. Transmission curves of imaging filters, together with the atmospheric transmission are shown in Figure 2.3 (see also Appendix B).

The K short or K_s filter is different from both the standard K filter and the K' filter defined by Wainscoat and Cowie (1992, AJ, 103, 332). The long wavelength edge of the K_s filter is similar to that of the K' filter, but the short wavelength edge is similar to that of the K filter. Thus, the K_s filter avoids both the atmospheric absorption feature at 1.9 μm and radiation from the thermal background beyond 2.3 μm. The difference between K_s and K is given by $K - K_s = -0.005(J - K)$.

Similarly, the J_s and J filters differ mostly in the long wavelength edge - the transmission of the broader J filter is in practice limited by the atmosphere and therefore, the photometry in the J filter

Filter Name	Filter Wheel	Central Wavelength (μm)	Width (μm)	Peak Transmission (%)
Z	1	0.9	0.140	
J	1	1.247	0.290	
J_s	1	1.240	0.160	
H	1	1.653	0.297	83
K_s	1	2.162	0.275	88
NB 1.061	1	1.061	0.010	
NB 1.083 HeI J	2	1.083	0.016	61
NB 1.187	1	1.187	0.010	
NB 1.215	2	1.215	0.018	
NB 1.257 [FeII] J	2	1.257	0.019	
NB 1.282 Pβ	2	1.282	0.019	
NB 1.644 [FeII] H	2	1.644	0.025	
NB 1.710	2	1.710	0.026	
NB 2.059 HeI K	2	2.059	0.028	81
NB 2.090	1	2.090	0.020	
NB 2.124 H_2 (S1)	2	2.124	0.028	78
NB 2.170 Brγ	2	2.167	0.028	71
NB 2.195	1	2.195	0.030	
NB 2.248	2	2.248	0.030	
NB 2.280	2	2.280	0.030	69
NB 2.336 (CO)	2	2.336	0.031	
GBF	1	0.925 cut-on	—	
GRF	1	1.424 cut-on	—	
Open	1 and 2	—	—	—
Closed	1 and 2	—	—	—

Table 2.2: The broad and narrow band filters available with SOFI.

is less stable than with the narrower J_s one. However, the J_s filter allows about ~20% less photons to reach the detector than the J filter.

2.3 Long Slit Spectroscopy

SOFI offers low and medium resolution, long slit spectroscopy. The large field objective is used in this mode instead of the spectroscopic one because the former is achromatic. There are three grisms available with SOFI: two low resolution grisms and a medium resolution grism.

Of the two low resolution grisms, one covers the region from 0.95 to 1.64 microns and the second covers the region from 1.53 to 2.52 microns. Both grisms are made of KRS5 (refractive index ≈2.44) and the entrance surface of both is inclined to the optical axis. The blaze angle of the grooves is equal to the apex angle of the prism. The wavelength ranges, the resolving powers and the resolutions of the grisms are given in Table 2.3.

The medium resolution grism gives about twice the resolving power of the two low resolution grisms. It is used with the H and K_s filters as order sorting filters in the 3rd and 4th orders to cover respectively the H and K atmospheric transmission windows. The wavelength ranges, the resolving powers and the resolutions of the grisms are given in Table 2.4. The wavelength ranges are defined by the H and K_s filters.

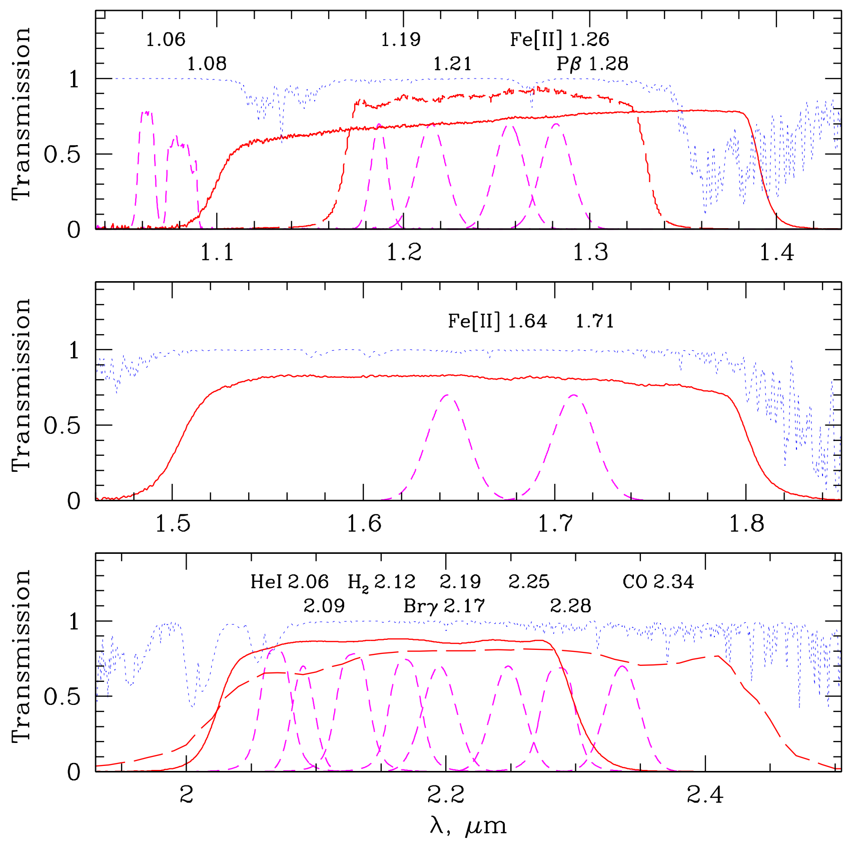

Figure 2.3: SOFI filters. The solid (red) lines indicate the currently available broad-band J , J_s , H and K_s filters. The short-dashed (magenta) lines are the available narrow-band filters. The long-dashed (red) lines show the soon to be commissioned J_s filter (top panel) and the typical broad K filter (Persson et al. 1998, AJ, 116, 2475; see their Table 10). The dotted (blue) line is the atmospheric transmission model for Mauna Kea, for Am=1.0 and water vapor column of 1mm (Lord, S.D. 1992, NASA Technical Memor. 103957; courtesy of Gemini Observatory). The data for the plot and a SuperMongo script are available from the SOFI web page.

The grism can also be used in the higher orders with the J and Z filters, However, there is significant overlap between these orders, so the useful wavelength range is limited. Furthermore, the line profile degrades in the blue, so that the resolution is not significantly better than that obtained with the low resolution blue grism.

Three slits of different fixed widths, 0.6, 1.0 and 2.0 arc seconds, are available. The slit length is 290 arc seconds.

2.4 Polarimetry

SOFI offers imaging polarimetry. A Wollaston prism in the grism wheel splits the incoming parallel beam into two beams that are perpendicularly polarized. The beams are separated by 48 arc seconds. Thus, an image taken with the Wollaston prism will contain two images of every object. To avoid sources overlapping, a special mask, consisting of alternating opaque and transmitting strips, can be inserted at the focal plane. Therefore, in a single exposure, at least half the field will be missing. So three exposures, with telescope offsets in between, are required to cover one field.

Grism Number	Order Sorting Filter	Wavelength Range (microns)	Resolving Power	Dispersion ($\AA$)/pixel
Blue	GBF	0.95-1.64	930	6.96
Red	GRF	1.53-2.52	980	10.22

Table 2.3: The wavelength range and the resolution of the low resolution grisms. The resolution is that measured for the 0.6 arc-second slit. The resolution scales inversely with the slit width.

Grism Order Name	Order Sorting Filter	Wavelength Range (microns)	Resolving Power	Dispersion ($\AA$)/pixel
3	K_s	2.00-2.30	2200	4.62
4	H	1.50-1.80	1500	3.43
5	J	1.20-1.28	1400	2.71
6	J	1.17-1.24	1400	2.22
7	Z	0.89-0.93	1400	1.87
8	Z	0.86-0.95	1400	1.58

Table 2.4: The wavelength range and the resolution of the medium resolution grism. The resolution is that measured for the 0.6 arc-second slit. The resolution scales inversely with the slit width.

The Wollaston prism is not achromatic, so the exact separation between the two beams is a function of wavelength. At J, the separation is 48.3 arc seconds, while at K_s, the separation is 47.4 arc seconds. The beam separation is also a function of position.

To measure the Stokes parameters and hence the degree and position angle of polarization a second set of images with the Wollaston prism rotated 45 degrees with respect to the first pair are required. This is achieved by rotating the entire instrument. The Stokes parameters are then determined as follows:

$$I = i(90) + i(0) = i(45) + i(135)$$

$$Q = i(0) - i(90)$$

$$U = i(45) - i(135)$$

where $i(\alpha)$ is the intensity of the source which transmits light that is polarized at angle α. We have assumed that the rotator is at a position angle of 0 degrees for the first measurement. This need not be the case.

The degree of linear polarization and the polarization angle are given by;

$$P = \frac{\sqrt{U^2 + Q^2}}{I}$$

$$\theta = 0.5 \times \tan^{-1}\frac{U}{Q}$$

To derive the correct value of θ, attention needs to be paid to the signs of U and Q.

This algorithm neglects instrumental polarization. Preliminary measurements indicate that the instrument polarization is 2%. As it is caused by the tertiary mirror, the vector defining the instrument induced polarization will rotate relative to the sky. A method to eliminate the instrumental polarization is outlined by Sperello di Serego Alighieri (1989, Proceedings of 1st ESO/ST-ECF Data Analysis Workshop).

Technical reports have been released, which describe in details this mode and its operation. They are available on the SOFI web page (Wolf, Vanzi & Ageorges 2002; `http://www.ls.eso.org/lasilla/sciops/ntt/so`

2.5 The DCS - Detector Control System

The DCS is made up of the detector, the front-end electronics, and the controller (IRACE = InfraRed Array Control Electronics).

The IRACE controller controls the detector front-end electronics and manages pre-processing of the data before sending it to the SOFI workstation. It includes an embedded Sparc and two sets of transputers. Further details on the IRACE system can be found at:

`http://www.eso.org/projects/iridt/irace/`.

The amount of data pre-processing depends on the readout mode. The readout modes available with SOFI are discussed below.

The detector used by SOFI is a Rockwell Hg:Cd:Te 1024x1024 Hawaii array manufactured by Rockwell Scientific, with 18.5 micron pixels. The array is read out in four quadrants. The average quantum efficiency is 65 % (Figure 2.4). The dark current is very low, 20 e^-/hour, and the readout noise with the IRACE controller in DCR (Double Correlated Read) mode is 12 e^-. In NDR (Non Destructive Read), values as low as $\sim$3 e^- have been reached with integrations of one minute. About 0.1% of the pixels are bad. An updated mask of bad pixels is available in the SOFI web page.

The gain of the array $\sim$ 5.4 e^-/ADU. The well depth of the array is around 170,000 electrons (32,000 ADU). Although the array non-linearity is limited to less than 1.5 % for a signal up to 10,000 ADU, we recommend that observers keep the exposure short enough so that the *background* does not exceed 6,000 ADU. This is due to the bias of the array, which has a complicated dependence on the flux when the flux is above 6,000 ADU.

NOTA BENE: A star of K$\sim$10 mag produces 9,000-10,000 ADU at the central pixel under seeing $\sim$0.6-0.7 arcsec and average conditions, in Large Field imaging mode. This is the case with many of the photometric standards and since these values are close to the non-linearity limit, the user may consider defocusing the telescope for standard star observations or switching to one of the imaging modes with finer pixel scale for observations that can not

The DCS has to cope with backgrounds that range from a fraction of a ADU/sec/pix, as seen in the spectroscopic modes to six hundred ADU/sec/pix, as seen during summer with the K_s filter and the large field objective. The high count rate from the background, particularly at K_s, limits a single integration to about 10 seconds, and it can drop down even to 6 seconds, depending on the humidity, clouds cover, etc. Thus, in order to accumulate sufficient photons without saturating the detector, the observer should acquires many individual integrations and then averages them on the fly into a final frame. The control system allows to do exactly that.

In this context, we define `DIT`, the *Detector Integration Time,* as the amount of time during which the signal is integrated onto the detector diodes, and `NDIT` as the number of detector integrations that are obtained and **averaged** together. These averaged frames make up the raw data, and in normal co-add mode, they are the smallest block of data presented to the user. So that the total exposure time of a single image (= single raw data file, available to the user) is `NDIT` x `DIT`. Note that the RTD (Real Time Display) can show either a single `DIT` or the averaged `NDIT` x `DIT`.

Additionally, some of the science templates allow the user to obtain several consecutive exposures of

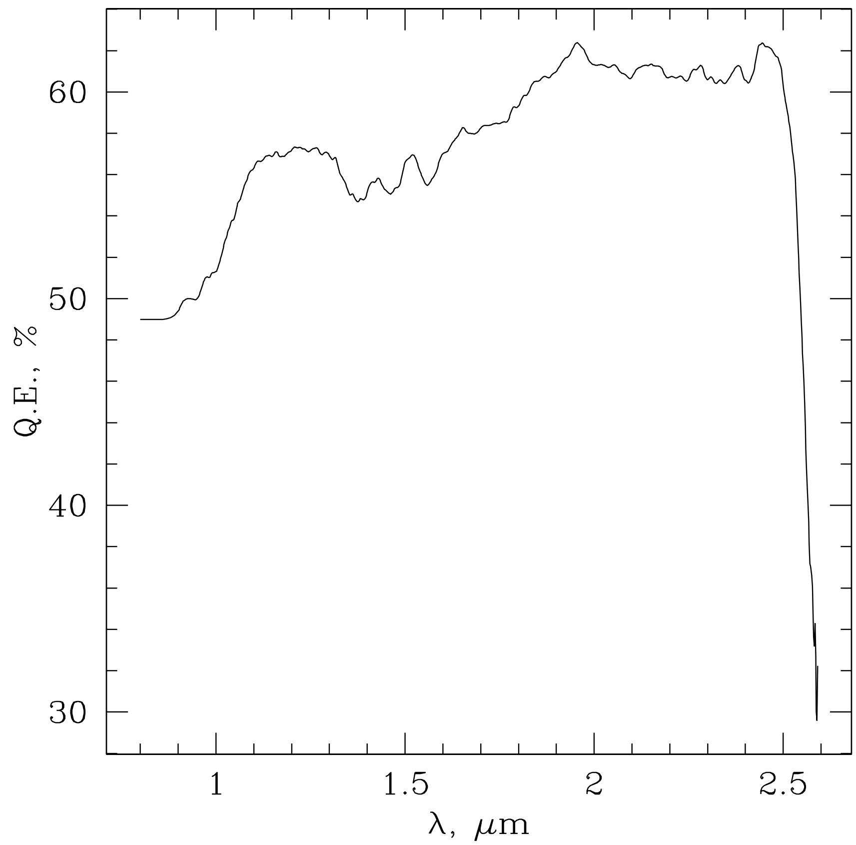

Figure 2.4: Quantum Efficiency of the SOFI detector at T = 78 K. The peak Q.E. is at 1.970 μm, and the long wavelength cut-off is at 2.579 μm.

`NDIT` x `DIT`, as defined by `NINT` and `NJIT` parameters.

NOTA BENE: The counts in a raw data file always correspond to `DIT` seconds. However, a single raw data file represents total integration time of `NDIT` x`DIT`, because the counts in the file are the average of `NDIT` sub-integrations, each of `DIT` seconds!

2.5.1 Readout Modes

Unlike optical CCDs, the charges in individual pixels of infrared detector arrays are not shifted from pixel to pixel during the read-out process. Instead, each pixel is independently read and each column is individually reset. This enables one to develop several readout methods. For SOFI, two readout methods are available: DCR (Double Correlated Read) and NDR (Non-Destructive Read). DCR incurs less overheads and is suitable for modes where the dominant source of errors is the Poisson noise of the sky emission: imaging and low resolution spectroscopy. NDR has a lower read-out noise and is suitable for modes for which the read-out noise is comparable to the other sources of error: low and medium resolution spectroscopy.

- **Double Correlated Read:** Here the voltage is sampled twice, once at the beginning of the integration and a second time at the end of the integration. This method is called Double Correlated Read or DCR for short. It is commonly used in high background situations where integrations are forced to be short. In principle this method is susceptible to 1/f noise; however, the Poisson noise from the background will be, by far, the most important noise source. The minimum integration time for SOFI in this mode is 1.183 seconds.

- **Non-Destructive Read:** In Non-Destructive Read or NDR the array is sampled several times after the reset. We will call the number of samples NSAMP. In other words, the array is read NSAMP times during each individual DIT. The flux in each pixel is computed by fitting a linear function to the voltage as a function of time. The fitted slope – equivalent to the photon rate – is then multiplied by the integration time. There are several ways the signal can be read in the NDR mode. The one used in SOFI concentrates the read-out at the beginning and at the end of the integration, in this way the noise is minimized. This mode is called Fowler sampling. Unfortunately, with the number of readings the glowing produced by the heat from the shift-registers at the border of the array increases. For NSAMP = 60 the photon noise of the glowing starts to compete with the read-out noise and above 60 becomes the dominant source of noise. For this reason the NSAMP **must not exceed 60**. To further minimize the noise, keeping NSAMP small, the analog signal can be sampled several times for each reading, this is done with the parameter NSAMPIX. The read-out noise is reduced approximately by the square root of the number of samples NSAMP. This method is also less susceptible to 50 Hz pickup noise. The drawback of the NDR is that it takes slightly longer to process the data although the disadvantage becomes smaller as the exposure time increases. The shortest integration time in this mode is given by $1.64 \times$ NSAMP. NDR is only available for the spectroscopic modes. For most applications we recommend NSAMP = 30 and NSAMPIX = 4.

There is a noiseless component of the signal introduced by the reset which is somewhat unstable a short time after the reset. Thus, there is a small delay of 100 ms between the reset and the first read. This component decays with time, for this reason dark frames taken with long DIT have negative counts.

The Hawaii array, like the NICMOS III array is read out simultaneously in four quadrants. This leads to a characteristic jump in the count level at rows 1 and 513. This jump depends on the DIT and on the incident flux on the array. The jump is stable with time, and it disappears after the sky subtraction.

2.5.2 Features on the Detector

There is a number of features of the detector. The most prominent ones are a few circular depressions in the quantum efficiency with radius if ∼20-40 pixels. Their presence is not a source of concern because they flat-field out. In addition, there are some variable features, i.e. dark regions caused by dust particles that have fallen inside the instrument. Rotation of the instrument can remove them.

Occasionally, the detector array shows elevated noise pattern. The effect is probably caused by interference and despite the replacement of most electronic components, it remained unreproducible. Usually, it is confined to a single quadrant. The noise amplitude is only a few ADU and it adds negligible error in imaging or low-resolution spectroscopy mode. However, in high-resolution spectroscopy mode, especially when observing faint targets, it is advisable to select nodding and jittering parameters placing the target in the unaffected quadrants.

2.5.3 Windowed Reading

The SOFI detector can be windowed. Each window is defined by the starting pixel coordinates and the size of the windowed region. The entire array is still read out by the IRACE controller; however, only the windowed section is transferred to the workstation. This leads to a slight overhead decrease. For position angle PA = 0 deg starting coordinates of (1,1) correspond to the North-East corner and they increase toward South-West, respectively.

2.6 Calibration Unit

The SOFI calibration unit is located inside the telescope adapter. It contains a halogen lamp for internal spectroscopic flat fielding, Xenon and Neon lamps for wavelength calibration. Line identifications are given in the Appendix A.

The halogen lamp is used to flat field spectroscopic data. These flats are called Nasmyth flats. Note that the Nasmyth flats introduce an extra spatial response by the lamp, that has to be removed by additional night sky spectroscopic flat.

The halogen lamp is **not suitable for flat fielding of imaging data**. Use the dome flat field lamp for this (see Sec. 3.5.2 for details).

2.7 Instrument Performance and the Exposure Time Calculator

Table 2.5 we list the approximate zero-point of the broad band filters with the large field objective as measured over many nights starting from July 1998 to May 2005. Limits are similar for the small field and spectroscopic objectives. For more recent detection limits in the spectroscopic modes and for detection limits with the narrow band filters, together with recent measurements of the ZPs, refer to the SOFI web page.

Filter	ZP	Average Background	Detection Limit	
		Mag. sq. arc second	Point Source	Extended Source
Z	22.6	...	...	...
J	23.2	15.5-16.1	22.7	22.1
J_s	23.1	...	...	...
H	23.0	13.4-14.7	21.8	21.4
K_s	22.4	12.8-13.3	20.8	20.4

Table 2.5: Measured SOFI performance for the broad band filters: 1 hour exposure.

The point source detection limits are based on the following assumptions:

- Signal to noise ratio of 5, computed over 21 pixels,
- Pixel scale: 0.288 arc seconds/pixel.
- 1 hour exposure made up of 60 one minute integrations.
- Seeing 0.75 arc seconds.
- Airmass 1.2
- Backgrounds of 16.0, 16.0, 14.2 and 13.0 in J, J_s, H and K_s, respectively.

The extended source detection limits were made for an aperture with a diameter of 3 arc seconds and for a S/N of 4.

The values of Table 2.5 can be re-scaled to different S/N ratios, fluxes (F) and integration times (t) keeping in mind that for background limited performances $S/N \propto F \times \sqrt{t}$.

Background limited performances are reached when ADU$\gg$30, assuming read-out noise 12 e^- in the double correlated read-out mode, and a gain of about 5.4 ADU/e^-

NOTA BENE: The detection limits given above vary with the background level which is strongly sensitive to the humidity and and air temperature. The background can easily change within 50%.

2.8 Instrumental Overheads

The fraction of time spent not collecting photons is defined as the instrumental overhead. A good conservative rule of thumbs states that it is typically about 30% of the integration time.

There are several sources of telescope and instrument overhead:

- acquisition overhead which depends on the instrument mode, the selected acquisition template, the brightness of the target, the angular distance from the previous target; in the simplest case of imaging it takes on average 3-5 min, the more challenging spectroscopic acquisitions can require up-to 5-10 minutes
- the time necessary to offset the telescope between different jitter positions and any remaining time to complete the last `DIT` that was started during the telescope offset; recall that the sequencer is not interrupted unless the `DIT` is changed; in case of guiding there is an extra overhead necessary to reacquire the guiding star; therefore, the intervals between the offsets have to be as long as possible, to minimize these losses and this can be achieved with increasing `NDIT` (i.e. `NDIT`×`DIT`∼2-3 min for imaging, in case of excellent sky conditions), but not too long as to compromise the sky subtraction
- there is a 0.1 second delay between the reset of the array and the first read at every `DIT`; this implies that to minimize the overhead the user should try to use as long `DIT` as possible (but not too long as to saturate the detector or to work in the non-linear regime above 10000 ADU)
- it takes 1 second to read out the array

It is difficult to give a precise estimate of the instrumental overhead, but here is a common example. A one hour exposure made up of 60 one minute, unguided exposures (with typical for H, K or K_s `DIT` = 10 and `NDIT` = 6) with telescope offsets for jittering in between will take a total of ∼80 minutes. Guided exposures will take 35 to 50% overheads.

Chapter 3

Observing in the IR

3.1 The IR Sky

Observing in the IR is more complex than observing in the optical. The difference arises from a higher and more variable background, by stronger atmospheric absorption and telluric emission throughout the 1 to 2.5 micron wavelength region.

Short-ward of 2.3 microns, the background in dominated by non-thermal emission, principally by aurora, OH and O_2 emission lines. The vibrationally excited OH lines are highly variable on a time scale of a few minutes. Pronounced diurnal variations also occur. The lines are strongest just after sunset and weakest a few hours after midnight. A complete description and atlas of the sky emission lines can be found in the paper Rousselot et al. (2000, A&A 354, 1134).

Long-ward of 2.3 microns, the background is dominated by thermal emission from both the telescope and the sky, and is principally a function of the temperature. The background in K_s can vary by a factor of two between the winter and summer months but is more stable than the J or H band background on minute-long time-scale. It also depends on the cleanliness of the primary mirror. Imaging in broadband K_s and the wide field objective can result in backgrounds of 600-700 ADU/sec, depending strongly on the temperature and humidity.

The IR window between 1 and 2.5 microns contains many absorption features that are primarily due to water vapor and carbon dioxide in the atmosphere. These features are time varying and they depend non-linearly with airmass. The atmosphere between the J and H bands and between the H and K bands is almost completely opaque. The atmospheric transmittance between 1 and 2.5 microns as seen by SOFI is plotted in Appendix B. As the amount of water vapor varies so will the amount of absorption. The edges of the atmospheric windows are highly variable which is important for the stability of the photometry in J and K_s filters.

These difficulties have led to the development of specific observing techniques for the IR. These techniques are encapsulated in the templates that are used to control SOFI and the telescope. In this section we link common observational scenarios with specific templates and we give some concrete examples. In later sections we discuss some finer points. The templates are described in detail in The SOFI TSF Parameters Reference Guide.

3.2 Imaging

It is not unusual for the objects of interest to be hundreds or even thousands of times fainter than the sky. Under these conditions it has become standard practice to observe the source (together with the inevitable sky) and subtract from it an estimate of the sky. Since the sky emission is generally variable, the only way to obtain good sky cancellation is to do this frequently. The frequency depends on the wavelength of observation (and respectively on the nature of the sky background emission) and on meteorological conditions. Ideally, one would like to estimate the sky more quickly than the time scale of the sky variations. While this could be done quickly with the traditional single- and especially double-channel photometers, the overhead in observing with array detectors and the necessity of integrating sufficient photons to achieve background limited performance are such that the frequency is of the order of once per minute. This sky subtraction technique has the additional advantage that it automatically removes offsets due to fixed electronic patterns (bias) and dark current.

NOTA BENE: The *sky* and the *object+sky* have to be sampled equally; integrating more on the *object+sky* than on the *sky* will not improve the overall signal-to-noise ratio because the noise will be dominated by the *sky*.

There are two standard techniques to estimate the sky. The first is appropriate for angularly large objects or crowded fields and the second is appropriate for angularly small (in comparison with the field of view) objects or uncrowded fields.

3.2.1 Selecting the best `DIT` and `NDIT`

Selecting the best `DIT` and `NDIT` is a complex optimization problem and it depends on the nature of the program: targets, required signal-to-noise, frequency of sky sampling, etc. Therefore, it is hard to give general suggestions and the users should exercise their judgment and discuss their choices with the support astronomer in charge of their run.

The first constraint is to keep to signal from the target on the linear part of the detector array dynamic range, which is bellow 10,000 ADU. The minimum `DIT` of 1.183 sec allows to observe without problem stars of ∼10 mag, under average seeing/humidity conditions. Keeping in the linear regime any bright stars that may have randomly fallen into the filed is also desirable because these stars will become a source of horizontal lines due to the cross-talk. The cross-talk is correctable well only if the sources that cause it are not saturated.

Unfortunately, it is not always possible to use small `DIT`, because the smaller `DIT` increases greatly the overhead – up to 50%, in the cases of 1.2-2 sec `DIT`. For comparison, observations with `DIT`=8 sec and `NDIT`=8 or 64 sec of integration in total, require about 80 sec so the overhead is 25%. The user may choose to accept the large overheads or the presence of increased "lines" in the image, that are hard (but not completely impossible) to correct.

The sky background is another factor that has to be accounted when selecting a `DIT`. It is the strongest in K_s band when it amount to 400-800 ADU per second, depending strongly on the humidity. The sky background can easily saturate the array by itself if the user selects a big `DIT` of 15-30 sec or more, depending on the filter.

Furthermore, this background is not constant. It varies on a time scale of a 1-3 minutes becoming a source of systematic uncertainties. To account for them the user must monitor these variations on the same time scale. This is done by alternatively observing the target and a clear sky field next to the target (the next sections contain some useful tips how to optimize these sampling in case of different types of targets). The frequency of the sky sampling is determined by the product `DIT`x`NDIT`, plus the overhead. The user should try to keep this time close to 1-2 min in average sky conditions or ∼3 min in exceptionally good conditions. To verify the choice of sky sampling the observer should frequently subtract sequential images from one another and monitor how large is the average residual. Ideally, it should be smaller than or comparable to the expected Poisson noise but this is rarely the case. Usually, a few tens or hundreds of ADU are considered acceptable by most users.

Finally, the total integration time is accumulated by obtaining a certain number of images, usually specified by the total number of exposures and/or the number of jittered images at each position, depending on which template is used. In case when relatively large integrations are necessary, it is simply a matter of increasing the number of exposures. However, in the cases when the total required time can be accumulated in less than 5-7 exposures it might become difficult to create a good sky for the sky subtraction, especially if the field is crowded because the sky image may contain residuals from the stellar images that will produce "holes" in the sky-subtracted data. This situation will require to increase artificially the number of exposures to 5 or 7. It might be possible to compensate this increase by decreasing correspondingly `NDIT` to keep the total integration time constant. Still, there will be some increase in the overheads.

Summarizing, under average conditions, for faint targets, one can safely use `DIT`=30, 15 and 10 sec for J, H and K_s filters, respectively. The narrow band filters can tolerate `DIT` of 60-120 sec. The array level will be dominated entirely by the sky. Brighter targets require to reduce these times down to 12, 8 and 6 sec for the broad band filters, for 12-15 mag stars, and all the way down to the minimum `DIT` of 1.183 sec for ~10 mag stars. The users may even have to consider splitting their observations into "shallow" and "deep" sequences, optimized for different magnitude ranges.

These issues are discussed again in Sec. 3.6.

3.2.2 Small Objects or Uncrowded Fields

If the object of interest is uncrowded stellar field, it is not necessary to take separate sky observations. In this case one can dither within the field and use the object frames to create sky frames. As a rule, the offsets should be greater than 10 arc-seconds, and if very deep exposures are required, the offset vector should not be replicated. For example, an offsetting scheme that is based on a rectangular grid of points will in a deep exposure show faint negative images arranged symmetrically around each real image. As a last resort, these can be minimized with appropriate masking during the data reduction.

Similar to the uncrowded fields, small objects can be observed in the same manner. In this case the user should make sure that the offsets are at least 2-3 times bigger than the size of the object.

A pseudo-random offsetting scheme (see sec. 3.6) is used in the template **SOFI_img_obs_AutoJitter**. The offsets are restricted to be within a square box centered on the object. The dimension of the box is defined by the parameter "`Jitter Box Width`." This and other parameters of the template are listed in Table 3.1.

If the value of the "`Return to Origin`" parameter is true (T), the telescope, at the end of the template, moves back to where it was at the start of the template. In general, auto-guiding is not required because of the frequent telescope offsets.

For a more detailed discussion about guiding options and the algorithm used to compute the offsets, please to refer to section 3.6.

If you wish to enter the offsets individually, use the template **SOFI_img_obs_Jitter**. This template is discussed fully in Appendix C.

3.2.3 Large Objects or Crowded Fields.

For objects larger than ~40% of the field or for very crowded fields, it is necessary to image the sky and object separately. Unfortunately, it is common that the sky frames will contain other objects, and it is not uncommon that one of these objects will be in the same region of the array as the science object. To avoid this it is standard to obtain several sky images on different locations, usually in the context of object-sky pairs. This technique assumes that the sky fields are sufficiently uncrowded

Parameter signature	Value
Exposure Name	Hubble_Deep_Field
DIT	10
NDIT	6
Number of exposures	60
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Filter wheel 1	K_s
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined Offset? (T/F)	F
Jitter Box Width (arcsec)	40
Return to Origin? (T/F)	T

Table 3.1: Parameters of the SOFI_img_obs_AutoJitter template with commonly used values.

that on any given position of the array most of the images will have sky, and only a minority will have objects. Clearly, minimum three sky images are necessary for this technique but the experience shows that a reasonable minimum number of the sky images (and respectively, the object-sky pairs) is 5-7, to ensure a good removal of the objects from the sky frames. Note that this may lead to an extra overhead because in some cases the `NDIT` has to be reduced artificially (contrary to the optimization strategy discussed in Sec. 2.8) to a number bellow the optimal, just to split the total integration into 5-7 images, adding an extra overhead for the telescope offsets.

This technique is encapsulated in the template called **SOFI_img_obs_AutoJitterOffset**. The parameters of this template are listed in Table 3.2. While preparing such observations, please keep in mind that the total duration of an imaging OB *in Service Mode* can not exceed 1 hour (in Visitor Mode the duration of an OB is not constrained). The example corresponds to the maximum duration acceptable.

Parameter signature	Value
Exposure Name	NGC6118
DIT	10
NDIT	6
Number of exposures	36
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Filter wheel 1	K_s
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined Offset? (T/F)	F
Jitter Box Width (arcsec)	20
Sky Offset Throw (arcsec)	600
Rotate Pupil? (T/F)	T

Table 3.2: The parameters of the template SOFI_img_obs_AutoJitterOffset with typical values.

In this template, one observes alternatively the object and sky. There are 36 exposures in total, 18 on the object and 18 on the sky. The sky positions are randomly chosen to lie on a circle that is centered on the object. The diameter of this circle is set by the parameter "`Sky Offset Throw`." Each of the six sky positions is different. Each of the six object positions are also different – they are randomly distributed within a square box that is centered on the object. The box size is set by the parameter "`Jitter Box Width`." Auto-guiding is set by the parameter "`Combined offset`." If selected, guiding is done when the telescope is pointing to the object field. As the NTT tracks very well and as one usually spends no more than a few minutes on a single position, is not recommended.

At the end of the template the telescope returns to the original position, making it especially convenient for obtaining a sequence of images in different filters on the same field.

The parameter "`Rotate Pupil`" is an option which allows you to rotate the instrument in between the sky an object positions so that the one obtains better sky cancellation. For imaging in filters with high backgrounds, that is the K_s and narrow band filters with central wavelengths greater than 2.2 microns, we recommend that you set this option to T (true).

For a more detailed discussion about guiding options, the algorithm used to compute the offsets, and the reasoning behind the option to rotate the pupil, please to refer to section 3.6.

If you wish to enter the offsets manually, use the template **SOFI_img_obs_JitterOffset**. If one wishes to use a more complex pattern that does not involve observing the object and the sky alternatively, use the either **SOFI_img_obs_Jitter** or **SOFI_img_obs_GenericImaging**. These templates are discussed fully in The SOFI TSF Parameters Reference Guide.

NOTA BENE: The offset to "clear" *sky* field introduces extra 130-150% overhead, because we have to spend on the *sky* the same amount of time as on the *object+sky*, plus the usual 30-50% overheads for readout, telescope offsets, etc. Therefore, it is recommended – if possible – to take advantage of the SOFI Large Field mode and to observe such targets in the same way as compact targets (see section 3.2.2).

3.2.4 Maps of Large Fields

To cover a large area of the sky with a map the template **SOFI_img_obs_AutoJitterArray** is available. This template allows to define an array of positions (`NEXPO`) through a list of offsets in RA and DEC and to randomly jitter (number of jitter positions defined by `NJIT`) around each of the offset positions. The `NJIT` images around each offset are completed before moving to the next offset position.

However, in some cases it is preferable first to obtain a single image at each offset position, then to "shift" the entire offset pattern by a small jitter and to repeat it. This can be done with the template **SOFI_img_obs_AutoJitterArray_1** that has identical parameters, takes the same number of images on the same locations as **SOFI_img_obs_AutoJitterArray** but differs only in the order in which these images are taken.

The template **SOFI_img_obs_AutoJitterArray** may be preferable if it is more important to make sure that at least some of the offset positions are observed with the required depth, while the template **SOFI_img_obs_AutoJitterArray_1** may be preferable if covering the entire mapped area (albeit at a shallower depth) has higher priority than the depth of the mosaic.

The parameters of both templates are listed in Table 3.3.

3.2.5 Imaging of Moderately Large Object

This section describes imaging of moderately large objects, i.e. objects comparable to the SofI field of view. We discuss this case after the mapping of large areas because it uses the same template

Parameter signature	Value
Exposure Name	SOFI_Map
DIT	10
NDIT	6
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
NJITT	6
NEXPO	9
Jitter Box Width (arcsec)	40
Filter wheel 1	K_s
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined Offset? (T/F)	F
Return to Origin? (T/F)	T
RA Offset List (arcsec)	0 450 450 0 -450 -450 0 450 450
DEC Offset List (arcsec)	0 0 0 -450 0 0 -450 0 0

Table 3.3: Parameters of the SOFI_img_obs_AutoJitterArray template with commonly used values.

SOFI_img_obs_AutoJitterArray_1 as the area mapping.

There are two distinct cases:

(i) Observations of "semi-extended" objects as large of a quarter to half of the SofI filed of view; these may be moderately distant galaxies, small Milky Way clusters or LMC/SMC clusters. They are too big for simple jittering mode observations but still leave room for more efficient observing strategy where the observer does not need to sample clear sky 50% of the observing time. Instead, the user can observe the sky simultaneously with the target, adopting clever offsets that would move the in the centers of the four quadrants, or two halfs of the array. In the latter case, a suitable rotation offset may be necessary to align the side of the array with the major axis of the object.

A typical example of a 4-point observation is shown in Figure 3.1. The figure shows the target – a round object with diameter 90 arcsec – as it will appear on the RTD and on the SofI images. The best choice is to use the template **SOFI_img_obs_AutoJitterArray_1**. As it is described in Section 3.2.4 this template allows the user to take a sequence of jittered images around user-defined positions: first, all positions are imaged ones, then a random jitter is added to the entire pattern and it is repeated as many times as necessary. Note that the offsets are executed **before** the images are taken, and the offsets are defined along RA and DEC, in arcseconds. On the figure, the images in the sequence are numbered to show the order in which the target will move during the observations. The zero number is the location of the target acquisition and it will be discussed further.

The parameters of both templates are listed in Table 3.4. Note that for 4-point observation the NEXPO parameter **must** be equal to four! Therefore, the total integration per position is controlled by the time spent per on each image (= DIT×NDIT, usually 1-3 minutes) and by the number of jittered images taken at each individual position NJITT. In this example, the total integration time is: $\mathrm{NJIT}\times\mathrm{NEXP}\times\mathrm{NDIT}\times\mathrm{DIT} = 12\times4\times10\times6{=}2880\,\mathrm{sec}$.

In general, the template allows to define manually the offsets for each individual image. However, this is inconvenient if the number of images is large. To simplify the matter, we suggest to the user to define a "closed" loop, where after four images the telescope points back to the original position. This means that the sum of the offsets along the RA is zero, same as the sum of the offsets along the

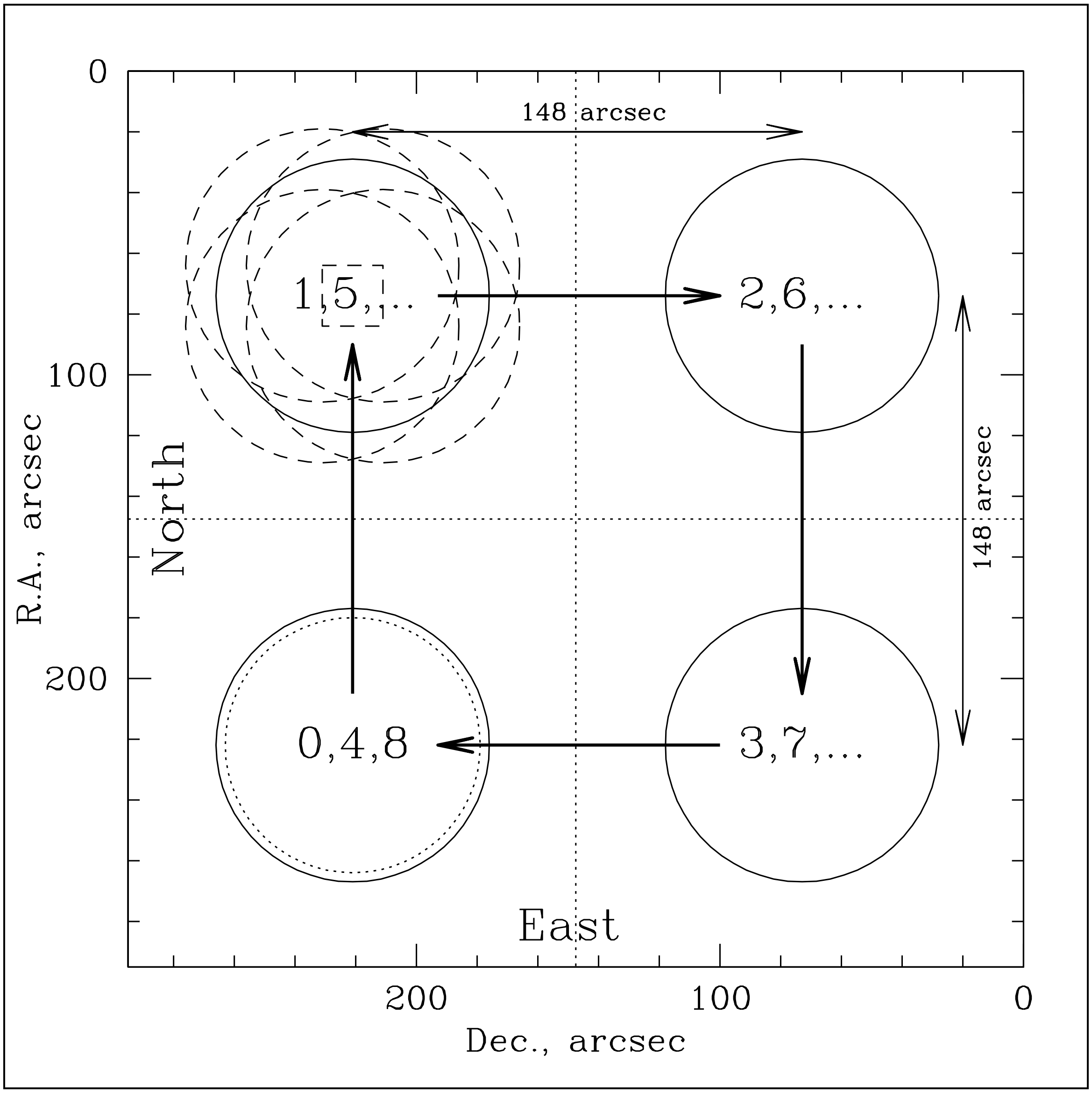

Figure 3.1: Example of 4-point observation scheme of a "semi-extended" objects without extra overhead for observation of clear sky. Remember, than although the target is moving on the RTD, it is really the telescope that is moving!

DEC.

Fortunately, the autojitter feature of the template ensures that the the next batches of four images will not be taken at exactly the same positions as the previous ones. In the example the jitter box is 20 arcsec, and for simplicity it is shown only on the first of the four positions. Four dashed circles show where the target would be if the random jitter offsets move the target center to the edges of the jitter box. This has to be remembered well, because too large a jitter box may move the target out of the field of view or it may lead to overlapping of the target edges in sequention images. The overlap is better to be avoided because it may affect the sky subtraction.

The user should try to keep the target as close to the center as possible without the allowing the overlap mentioned above. In fact, this example allows some modification: the offsets can be reduced from 148 to 110-120 arcsec and the jitter from 20 to 10 arcsec. The small jitter is acceptable because during every cycle we take four images at different array location reducing the effect from the bad pixels (the major reason for jittering in this case). Note that this is usually not the case

Parameter signature	Value
Exposure Name	SOFI_4-point
DIT	6
NDIT	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
NJITT	12
NEXPO	4
Jitter Box Width (arcsec)	20
Filter wheel 1	K_s
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined Offset? (T/F)	F
Return to Origin? (T/F)	T
RA Offset List (arcsec)	148 0 -148 0
DEC Offset List (arcsec)	0 148 1 -148

Table 3.4: Parameters of the SOFI_img_obs_AutoJitterArray_1 template with commonly used values for 4-point observation of a "semi-extended" object.

with **SOFI_img_obs_AutoJitter** and template observations of uncrowded targets where the jitter is needed to produce a sky image for the sky subtraction.

There is one more – albeit simple – complication in this observing strategy: the offsets are executed before the images are taken, so the acquisition must place the target at the location of the fourth image in the cycle. This is the position shown in the figure with a dashed circle and marked with zero. Finally, the thick arrows show the apparent movement of the target on the RTD from one position to another. North and East are also marked.

This example can easily be generalized - one can observe a slightly small target at five positions, including one at the center of the array. In this case NEXPO=5. On the contrary, an edge-on galaxy with a major axis of 3-4 arcmin a minor axis of 1-2 arcmin must be observed at only two array positions, so NEXPO=2. In this case the user should define a suitable rotator offset to align the major axis with the array edge.

(ii) Observations of objects that need 2-3 fields to cover the entire target with additional images to sample the sky.

In principle, the template **SOFI_img_obs_AutoJitterOffset** can accommodate such observations if they are carried in a sequence of one field at a time. However, this means 100% overhead for the sky sampling. Instead, the user can reduce the overhead by alternating between one sky position and two-three target positions. A typical case is observing a large 6-10 arcmin galaxy in a sequence: sky - target field 1 - target field 2 - sky - target field 1 - target field 2 - sky - ... This is a 3-point pattern.

One can even alternate between two or more differnet sky positions, to improve the sky subctraction: sky1 - target field 1 - target field 2 - sky2 - target field 2 - target field 1 - sky1 - ... The last pattern is in effect a 6-point sequence. An example for this observation scheme is given in Figure 3.2 and the offsets are listed in Table 3.5. Note that the rotation offset has to be defined in the acquisition template. Also, the acquisition has to put the telescope at the location marked on the figure with zero. However, the first image in the sequence is actually a sky, on the location marked with number one. The parameter NEXPO has to be set to six. The sequence in which the images are taken is shown in the figure on the right. The target is marked with thick dark line, and it is covered by two overlapping field. The jitter boxes around each position are not shown. One 6-point cycle will obtain two images of 1 min at each target field, 12 cycles will accumulate 24 min of integration on each of the two galaxy fields and 12 min on each of the two sky fields. The total observation will require about 1.5hr, including the overheads.

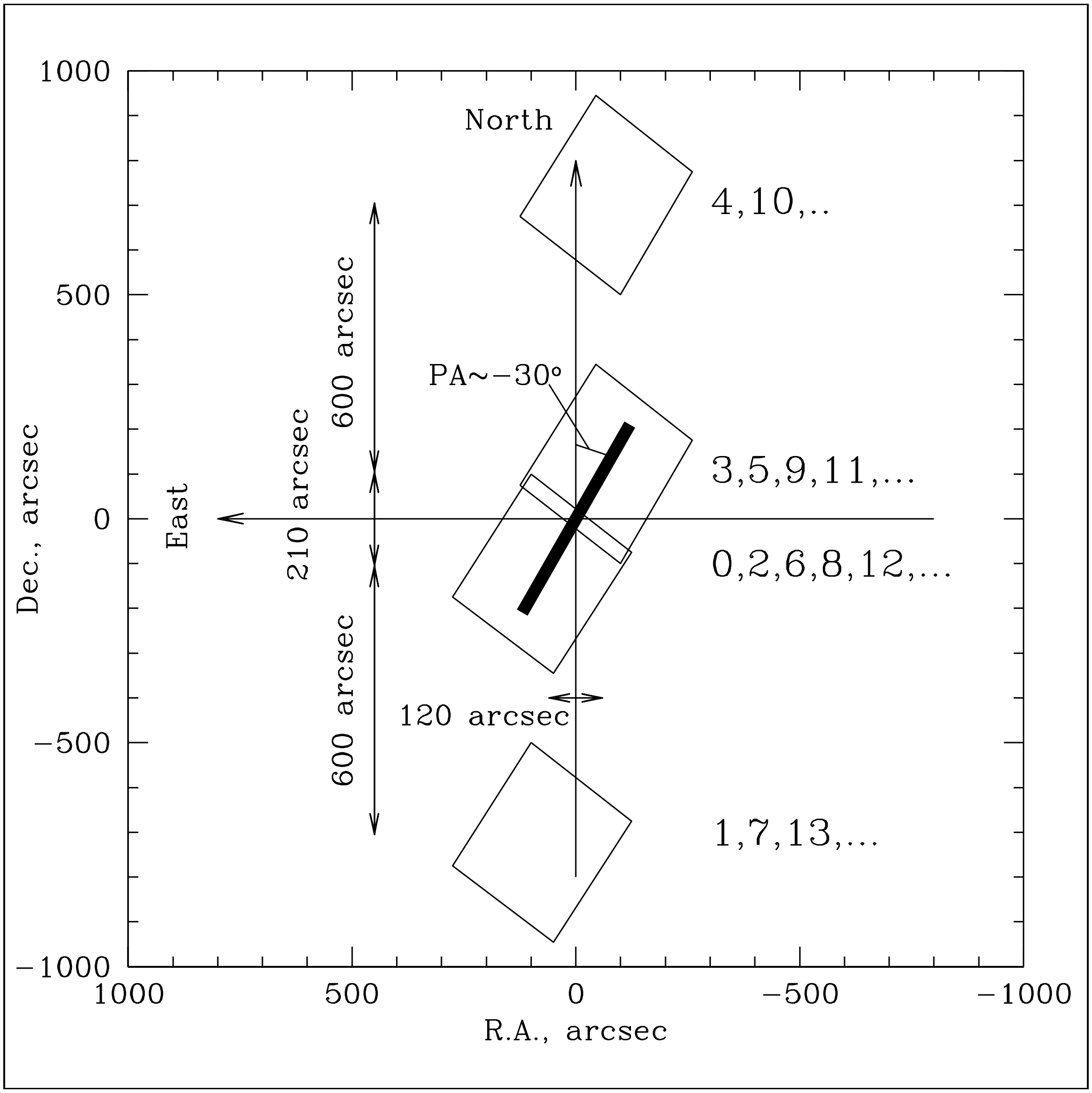

Figure 3.2: Example of 6-point observation of "semi-extended" objects alternating between two target field and one of two different skies.

Nota bene: The reduction of data obtained with the patterns described in this subsection is usually more complicated and requires special attention and more manual intervention than the "classical" observations! In addition, the sky sampling is rarefied. However, in most of the cases these are small prices to pay for 20-30% more data. The users must read carefully Section 5.2.4 where the sky subtraction is described.

Parameter signature	Value
Exposure Name	SOFI_6-point
DIT	6
NDIT	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
NJITT	12
NEXPO	6
Jitter Box Width (arcsec)	10
Filter wheel 1	K_s
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined Offset? (T/F)	F
Return to Origin? (T/F)	T
RA Offset List (arcsec)	0 0 -120 0 0 120
DEC Offset List (arcsec)	-600 600 210 600 -600 -210

Table 3.5: Parameters of the SOFI_img_obs_AutoJitterArray_1 template with commonly used values for 4-point observation of a "semi-extended" object.

3.2.6 Standard Stars

The IR window between 1 and 2.5 microns contains several large absorption features that are primarily due to water vapor and carbon dioxide in the atmosphere. The edges of the atmospheric windows are highly variable. Unfortunately, the edges of some IR filters, particularly J and K_s, are defined by these absorption features rather than the transmission curves of the filters themselves. Thus, when the column density of water vapor is variable, accurate photometry can be difficult to achieve. On good nights (generally when the humidity is low and it is cold) it has been possible to achieve better than 1% photometry; however, on most nights this should be considered as the best limit and the typical accuracy is 3-5%. Good planing of the observation and careful data reduction has allowed some users to reach with SOFI relative photometry of ~0.3%!

To get good photometry you should choose standard stars that are as close as possible to your program objects and you should observe them before and after you observe your program objects. The classical, optical method of determining extinction coefficients by observing standards over a wide range of airmasses works less well in the infra-red as the extinction co-efficients are generally not a linear function of airmass and may vary with the conditions, i.e. with the humidity.

During the night you should observe at least three different standards and you should observe at least one standard every two hours. On nights where the humidity (which is a rough measure of the water vapor column) is varying considerably, let's say by 40% in one hour, you will need to observe standards more frequently.

When observing standards, two or more images (typically five: one in the center of the array and four in the centers of each quadrant) of the standard star are obtained with a telescope shift(s) in between. In this way one image can be used as the reference sky of the other(s). If several images are obtained, the uniformity of the flat-field illumination can be checked.

Several standard star lists are currently available, but it should be noted that each list was created using detectors and filters that differ from the detectors and filters used with SOFI. Note also that most standards were observed with single channel photometers with very wide apertures. Thus close companion stars were probably included. The standards listed in Carter and Meadows (1995, MNRAS, 276, 734) have proved to be very useful, although they may prove to be too bright for SOFI, and to require defocussing the telescope. The more recent NICMOS standards by Person et al. (1998, AJ, 116, 2475) are more suitable as one does not need to defocus the telescope, except for seeing better than 0.6 arcsec. They are the standards of choice for most observers. Predefined OBs are available at the telescope for most of these stars. A list of references to these and other standard star lists as well as useful papers regarding the transformations between one photometric system and another are available from the SOFI web page.

It is important that you take care where the standard star lies on the array. Use the RTD (Real Time Display) to find areas that are clear of bad pixels. Furthermore, check if other objects are in the field. The offset between exposures should not be such that other objects in the field interfere with flux of the standard when one frame is subtracted from another. Alternatively, the standard can be observed in several different parts of the array. A pattern of five exposures with the standard observed once in the center of the array and once in each of the quadrants is one example. Table 3.6 demonstrated the usage of the **SOFI_img_cal_StandardStar** template.

Parameter signature	Value
Exposure Name	sj9104
DIT	5
NDIT	10
Number of exposures	5
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Filter wheel 1	J
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined Offset? (T/F)	F
Return to Origin? (T/F)	T
X offset list (arcsec)	0 75 -150 0 150
Y offset list (arcsec)	0 75 0 -150 0

Table 3.6: Parameters of the standard star template with commonly used values.

In this template the offsets are along array columns and rows and the units are arc-seconds, unlike other templates where the offsets are given along the RA and Dec. The offsets are relative. This template is very similar to the template **SOFI_img_obs_Jitter**. Indeed, one can use the **SOFI_img_obs_Jitter** template to do the same observation; however, we strongly encourage observers to use the **SOFI_img_cal_StandardStar** template as it is both easier to use and it tags the resulting images as standard star frames for archiving purposes and for easier identification by the zero point calculation tool available at the telescope.

In general is not required for standard star observations, and it is useful to set the "`Return to Origin`" parameter to true.

3.3 Polarimetry

In Polarimetry, a Wollaston prism and a mask wheel consisting of alternating opaque and transmitting strips are inserted into the beam. The widths of the transmitting sections are about 40 arc seconds, whereas the widths of the opaque sections are slightly larger. Thus, to cover the whole field one needs to take three separate images shifted by 30 arc seconds from each other. This techniques is embodied in the template **SOFI_img_obs_Polarimetry**. The parameters for this template are listed in Table 3.7.

Parameter signature	Value
Exposure Name	Planetary_Disk
DIT	1.8
NDIT	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of exposures	3
Filter wheel 1	J
Filter wheel 2	open
Combined Offset? (T/F)	F
Return to Origin? (T/F)	T
X offset list (arcsec)	0 0 0
Y offset list (arcsec)	-64 32 32
Rotator Offset	0

Table 3.7: Parameters of the polarimetric template with commonly used values.

This example takes three exposures in the J band. By default, the polarimetric mode uses the large field objective. Offsets are relative to array rows and columns, are independent of the rotator angle and are in arc-seconds. In this example, three exposures with offsets along the Y-direction are taken. In this way, an entire field can be covered. Observers may wish to include additional exposures with offsets in the X-direction to help with sky subtraction.

To measure the Stokes parameters and hence the degree and direction of linear polarization, one needs at least one additional set of observations with a position angle different from the first. The usual practice is to take two sets of observations with a rotational offset of 45 degrees. This can be done with the `''Rotator Offset''` parameter. The approximate rotation centers for the imaging modes are listed in Table 3.8.

Objective	Rotation Center (x,y)
Large Field	517, 504
Small Field	501, 505
Spectroscopic Objective	537, 502

Table 3.8: Approximate mechanical rotation centers for the imaging modes. Note that these values change after each instrument intervention.

There are two ways to do this. In the first method, one includes two observation templates for each polarimetric observation, one with the `''Rotator Offset''` angle set to zero and the second with the `''Rotator Offset''` angle set to 45. Alternatively, one can set the rotator angle through the acquisition template (See Appendix C) and keep the `''Rotator Offset''` angle zero in both case. Since the rotator axis does not correspond to the center of the array, the later method is preferable when one is trying to determine the linear polarization of a single object. For those who wish to map the polarization over a large field, either method can be used.

3.4 Spectroscopy

3.4.1 Small Objects and Uncrowded Fields

In spectroscopy, like imaging, accurate sky cancellation is important. If the object is small enough, the object can be observed at different slit positions. Sky cancellation is then achieved by subtracting one frame from another. This is a very efficient method because it is not necessary to spend extra time integrating off the target. This technique is embodied in the template **SOFI_spec_obs_AutoNodOnSlit**. Typical parameters for this template are listed in Table 3.9.

Parameter signature	Value
Exposure Name	Hubble_Deep_Field
DIT	60
NDIT	3
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Spectro Mode	LONG_SLIT_RED
Which Slit	long_slit_1
Combined Offset? (T/F)	T
Jitter Box Width (arcsec)	10
Return to Origin? (T/F)	T
Nod Throw Along Slit (arcsec)	60
NINT	3
Number of Cycles	4

Table 3.9: Parameters of the template SOFI_spec_obs_AutoNodOnSlit with commonly used values.

In this template the telescope nods the object between two positions along the slit that are "`Nod Throw Along Slit`" arc seconds apart. For convenience we will call one of these positions, position A and the other position B. At position A the object is observed for 9 minutes and the observer will receive 3 frames (specified by `NINT`), each the average of 3 (specified by `NDIT`) exposures of 60 second (specified by `DIT`). The telescope then moves to position B, where it again integrates for nine minutes producing three frames, each the average of three 60 second exposures. This completes one cycle. The number of A-B pairs – also called cycles – is defined by the parameter "`Number of AB or BA cycles`." In this particular case the number of cycles is 4, so the total exposure time is $60^{sec} \, x \, 3 \, x \, 3 \, x \, 2 \, x \, 4 = 72$ minutes. If the number of cycles is greater than 1, the telescopes moves in the following pattern: A, B, B, A, A, B, B, A, etc. Between consecutive A-A or B-B positions, there is no telescope offset, but one can include random offsets between consecutive A-B or B-A positions. In other words, every A-B or B-A cycle can be shifter with respect to the previous. The size of the region along the slit, in which are placed the random offsets, is defined by the parameter "`Jitter Box Width`." In the example given here the 1st and 2nd A positions will differ. Additionally the 1st and 3rd B positions will also differ.

In principle, the nodding frequency should be similar to that used during direct imaging. However, the desire to reach background limited performance forces longer exposures in the spectroscopic modes. As a general rule, one should limit the time spent at any one position to less than 15 minutes.

Although guiding is optional, we recommend that you guide. To do so, set the parameter "`Combined offset`" to true.

The Non Destructive Read-Out is recommended for faint objects that require long `DIT`. This is done with the templates **SOFI_spec_obs_AutoNodNonDestr** and **SOFI_spec_obs_GenSpecNonDestr**. In addition to the parameters of Table 3.9 these two templates include those showed in Table 3.10. The array is read within each `DIT` a number of times equal to `NSAMP`, and for each read-out the signal is sampled `NSAMPIX` times. The minimum `DIT` that can be used for a given `NSAMP` can be calculated, in seconds, is `NSAMP`×1.64 sec.

Parameter signature	Value
NSAMP	30
NSAMPPIX	4

Table 3.10: Parameters in the templates with Non Destructive Read-Out and commonly used values.

3.4.2 Extended Objects and Crowded Fields

For more complex nodding patterns or for observations of either extended objects or crowded fields, please use the template **SOFI_spec_obs_GenericSpectro**. This template is discussed in detail in Appendix C. It allows to place the slit on a user-defined sequence of positions, alternating between the *object+sky* and the *sky*.

Similar to the imaging of extended objects, an effort should be made to take advantage of the large slit length of 4.92 arcmin, to obtain observations with the simple nodding procedure described above, because the integrating of the clear sky increases the total time spent on the object by factor of two, for the same integration time on the target.

NOTA BENE: Frames taken with the NDR mode must be flat-fielded using dome flats taken with the same mode. For this reason a specific templates exists: **SOFI_spec_cal_DomeFlatNonDestr**.

3.4.3 Telluric Standards and Flux Calibration

The issue of flux calibrating IR spectra is still very much an issue of some debate. This section is written not as the definitive method to flux calibrate IR spectra, but rather it is written to illustrate the problems involved, and various methods for their solution.

As the IR window is dominated by time varying atmospheric absorption features that depend non-linearly with airmass, **it is necessary to divide object spectra with the spectrum of what we shall call an telluric standard**. The standard should be at an airmass that is as close as possible to that of the science target (usually $\Delta \sec z \leq 0.05$-0.1), it should be observed immediately before or after the target, and it should be observed with the same instrument set up (grism, slit, objective, etc.). From technical point of view, the telluric standards are observed in exactly the same way as the science targets. Since they are usually bright stars with no nearby companions of comparable magnitude, the template **SOFI_spec_obs_AutoNodOnSlit** is perfectly suited for this.

It is very important that object and standard star spectra are accurately aligned. A small misalignment will result in poor cancellation of the atmospheric absorption features. Misalignment could be caused by slit misalignment in between the observations, by instrument flexure or, when the seeing is smaller that the slit width, by inaccurate centering of objects on the slit. In general, this problem can be remedied later during the data reduction by re-aligning of the spectra: first by using the telluric features to determine the offset in wavelength direction, and second - by geometric transformation of the image in spatial direction. However, these are complicated and time-consuming steps, that involve heavy modification of the data prior to any scientific measurements, and it is preferable to avoid them, if possible.

The division by the telluric standard introduces into the target spectrum a number artificial "emission" features because of the intrinsic absorption features of the telluric standard itself. By choosing carefully the spectral type of the telluric standards one can minimize the number of such features but there are no stars with completely featureless IR spectra and therefore some such "emissions" will always remain. To remove them, **after the division by the telluric standard, one should multiply by the absolute spectral energy distribution of the telluric standard**. However, this information is usually not available, so one has to model the spectral energy distribution of the standard. For hot stars, a blackbody fit to the star may be appropriate, but for stars of spectral type later than B, a more accurate description of the energy distribution may be required.

Another possibility is to use a solar analog for telluric standard, taking advantage of the fact that the true intrinsic IR solar spectrum of the Sun is available. It was corrected by observing the Sun at different zenith angles and extrapolating to sec$z = 0$ – extremely time-consuming technique that is not reasonable to the usually faint science targets. The IR Solar spectrum is available from the National Solar Observatory ("An atlas of the solar spectrum in the infrared from 1850 to 9000 cm-1" Livingston W. & Wallace L. N.S.O., Technical Report #91-001, July 1991). A more detailed description how to use solar analogs as telluric standards and an IRAF-based tool can be obtained from Maiolino, Rieke & Rieke (1996, AJ, 111, 537; web-sites `http://www.arcetri.astro.it/~maiolino/solar/solar.html` and `http://nicmos2.as.arizona.edu/~marcia/solar/`). This page contains lists of stars with reliable spectral class determinations that can be used as telluric standards.

The final step is to flux calibrate the object spectrum. The flux calibration is done by **integrating the object spectrum over one or more broadband filter band-passes and scaling the result with the respective broadband magnitudes**. This method typically gives accuracy of order of 5-10%. It is very different to what is done to flux calibrate spectra in the optical. In the optical, atmospheric absorption is a relatively smooth function of wavelength, so it is sufficient to divide extracted spectra by a smoothed standard star spectrum and then multiply by the smoothed absolute energy distribution of the standard. In the IR, accurate spectroscopic standards do not exist. For an example of IR flux calibration in the more general case of extended objects see Ivanov et al. (2000, ApJ, 545, 190).

The choice of which standard to use depends on which part of the spectrum is of interest. All stars have absorption lines, so the idea is to choose a star which does not have strong features near the wavelength of interest. Hot stars provide relatively featureless spectra; however, they have strong hydrogen absorption lines, so they should not be used as flux calibrators if the region around the hydrogen lines is of interest. Later type stars such as G stars have weaker hydrogen lines, but are contaminated by multiple weak absorption lines. These stars have the additional advantage of being very numerous. Stars of later type should not be used as these stars contain numerous weak lines throughout their spectra. However, such stars have very weak hydrogen absorption and may be usefully employed to determine the strength of hydrogen absorption in the hot stars. In general, IR standards are significantly brighter than optical standards, nevertheless, stars should be fainter than seventh magnitude.

An moderately-high resolution IR spectral library for stars withe well-known parameters, including spectral types, is available from Ivanov et al. (2004, ApJS, 151, 387).

A list of O, F and G type stars selected from the HIPPARCOS catalog, with magnitudes appropriate for SOFI spectroscopy is available at the telescope and on the SOFI web page, together with web-based tool for automated search for stars with given spectral type and brightness near the science target (`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/IRstandards/index.html`). A similar tool, with extra capability to create automatically OBs for observing of telluric standards, is available on the SOFI instrument workstation but we recommend that the user creates their own OBs with the P2PP tool.

Nota Bene: Until recently IR spectrophotometric standards were not available. How-

ever, Cohen et al. (2003, AJ, 125, 2645) published "supertemplates" for a series of 33 stars, that span wavelength range from the UV to mid-IR (40 μm). The preliminary tests show excellent agreement between the synthetic photometry derived from these spectra and the observed magnitudes of the stars. Pending further tests, this spectral library may prove extremely useful for flux calibration of IR spectra.

3.5 Calibration Frames

3.5.1 Darks (Biases)

The concept of bias frames with IR arrays does not have the same meaning as CCD bias frames. With IR arrays, a zero second exposure is not possible. It is better to think of all exposures without direct illumination as dark frames. Note that in this context the biases are integral and indistinguishable part of the darks.

Dark frames are taken with the template **SOFI_img_cal_Darks**. The parameters for this template are listed in Table 3.11.

Parameter signature	Value
Exposure Name	Dark_Frames
DIT LIST	10 10 20 20 10 10
NDIT LIST	6 6 3 6 3 6
Number of exposures	12
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1

Table 3.11: Parameters in the SOFI_img_cal_Darks template with commonly used values.

In this template, one can enter a list of `DIT`s and `NDIT`s. If the number of exposures is greater that the number of elements in either of these lists, the list is repeated until the correct number of exposures have been completed.

The structure seen in the darks is quite complicated. In general, it is not a linear function of time. The signal is made of several components: shading, a component which depends on the `DIT` and on the incident flux; heat from the readout amplifiers, commonly referred to as amplifier glow; and classical dark current from the random generation of electron/hole pairs. The heat status from the readout amplifiers is a function of the number of reads only, whereas the dark current is a linear function of the time.

Other than depending on the `DIT`, the shading pattern seen in darks frames also depends on the incident flux. Thus, subtracting a dark frame from a science frame with the same `DIT` will not remove the shading pattern perfectly. This issue is discussed in more detail in the next section.

The experience has shown that the best way to remove the dark current is by taking data in exactly the same way and with exactly the same exposure time as the science observations. This is routinely done for the removal of the sky emission, so the removal of the dark is naturally removed when the sky is removed. The only case when the removal of the dark remains an issue is the flat fields (see the next section for discussion).

Darks appear to be stable over the period of a typical observing run. Thus, it is sufficient to take darks only once during the run, or more often – as a verification of the detector array status.

3.5.2 Flat Fields

As in the case of visible observations, one must correct for differences in pixel sensitivities. The method for creating flat fields is identical in both the spectroscopic and imaging modes. They are created by exposing alternatively an illuminated and an unilluminated dome panel. The flat-field images are constructed from the difference of the two, normalized to one. This technique is especially important when working beyond 2.3 microns, where it removes the thermal component of the signal, which does not depend on the intensity of the flat-field lamp. Spectroscopic flats must be taken with the same slit as the observations.

Imaging flat-fields can also be obtained from the twilight sky or from the observations themselves. However, dome flats represent better the low frequency sensitivity variations of the array.

Twilight spectroscopic flats cannot be used to flat field your data, although they can be used to determine the slit transmition function for spectroscopy of extended sources. The slit transmition function describes the transmission variation along the slit. It is usually affected by magnetized or sticky dust particles that attach to the slit edges. These particles can make the slit effectively narrower. Normally, steps are taken to clean the slit during interventions so the slit transfer function is highly uniform. This effect can be neglected for spectroscopy of point sources.

Spectroscopic flat fields can be taken with the halogen lamp in the calibration unit (Nasmyth flat). Again, one takes an image with the lamp on and off. The flat is the difference between the two, normalized to unity. The optical path length between the Nasmyth flat field lamp and the front window of SOFI is considerably smaller that the path length between the incandescent lamp on the floor of the dome and the front window of SOFI. Thus, one will see less of the strong atmospheric absorption features in the Nasmyth flats.

There are four templates to create dome flat fields, two for imaging **SOFI_img_cal_DomeFlats** and **SOFI_img_cal_SpecialDomeFlats**, and two for spectroscopy **SOFI_spec_cal_DomeFlats** and **SOFI_spec_cal_DomeFlatNonDestr**. Please note that the last template must be used ONLY to flat frames taken with the NDR Mode. In Table 3.12 is an example for imaging dome flats.

Parameter signature	Value
Exposure Name	Imaging_Dome_Flats
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of exposures	1
DIT LIST	3
NDIT LIST	60
Filter wheel 1	J
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING

Table 3.12: Parameters in the SOFI_img_cal_DomeFlats template with commonly used values.

The template actually takes four exposures in total: the first with the lamp off, then two exposures with the lamp on and then a final exposure with the lamp off. The intensity of the dome flat field lamp is controlled by a panel on the *tcs* machine. The instrument operator or the support astronomer will adjust the voltage until a level of a few thousand (usually 3000-4000 ADU) counts level is reached when the lamp is on.

In this template, one can enter a list of `DITs`, `NDITs`. If the number of exposures is greater that the number of elements in either of these lists the list is repeated until the the correct number of exposures have been completed. **Note that each "exposure" generates a sequence of 4 frames**, as explained before. If the parameter `"Number of Exposure"` is > 1 a corresponding sequence of frames will be generated. The template **SOFI_spec_cal_DomeFlatNonDestr** contains in addition the parameters of Table 3.10.

It was pointed earlier that shading, one of the components that make up a dark frame, is a function of the incident flux. This means that the method of creating dome flats described above does not remove perfectly the shading pattern. The effect for most observations is small, and manifests itself as a discontinuity of a few percent in the ZP across the center of the array. For most programs, this is not a major problem. Nevertheless, we have developed a technique to remove this residual, and this technique is embodied in the template **SOFI_img_cal_SpecialDomeFlats**. This template, in addition to the four frames taken with the template **SOFI_spec_cal_DomeFlats**, takes frames with the mask partially obscuring the array. Therefore, each exposure generates a sequence of 8 frames. In addition to them, 1-2 or more images are taken at the beginning in order to adjust and check the illumination level (set to 4000-6000 ADU), so the total number of the obtained images by this template may vary. Note that only the last 8 images are actually the flat field. Half of this sequence is shown in Figure 3.3. If the parameter `"Number of Exposure"` is > 1 a corresponding sequence of frames will be generated (so generally, use 1). These frames are used to estimate the shading. Further details are given in the section describing data reduction.

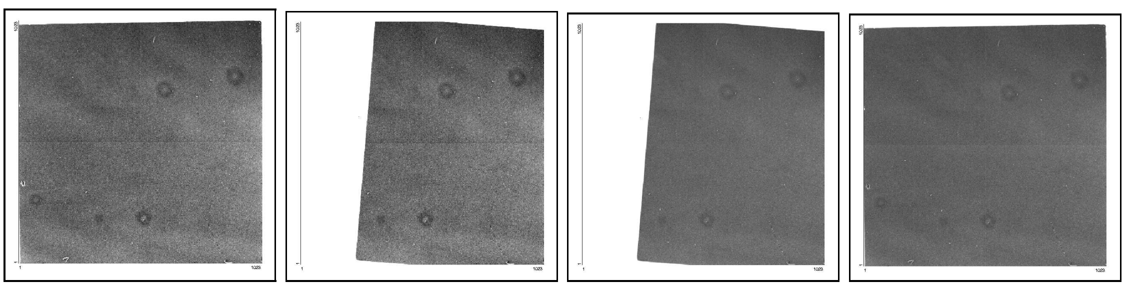

Figure 3.3: Examples of Special Dome Flat images. From left to right: lamp off, lamp off with mask, lamp on with mask, lamp on.

Flat Field frames for Large Field imaging with broad band filters are taken by the observatory staff on average once a months, and they can be downloaded from the SOFI Web page.

The stability of the flats was studied over a period of about a year, and it appears the degradation over time is minimal as can be seen in Figure 3.4. Therefore, it's not necessary to take flats every day during, especially if high precision photometry is not required to achieve the scientific goals of your program. However, it is advisable to take at least two sets of flats to check their consistency.

3.5.3 Illumination Corrections

It is often the case that the flat field generated from the dome, the twilight sky or the night sky itself does not represent completely the low frequency sensitivity variations of the array. In other words, the dome flat field contains a residual large scale variation that is usually due to the fact that the illumination of the screen can never represent accurately the illumination of the sky. In addition, the illumination of the screen can change with time due to the variations in the lamps used to illuminate it, and due to variation of the screen and dome temperature (for $\lambda \geq 2.3$ micron).

This problem can be solved by observing a bright star (preferably a standard) in a rectangular grid pattern of 9-16 positions across the array. After sky subtraction and flat fielding with the uncorrected flat, the intensities (not the magnitudes!) are fitted with a low order polynomial. Next, the surface

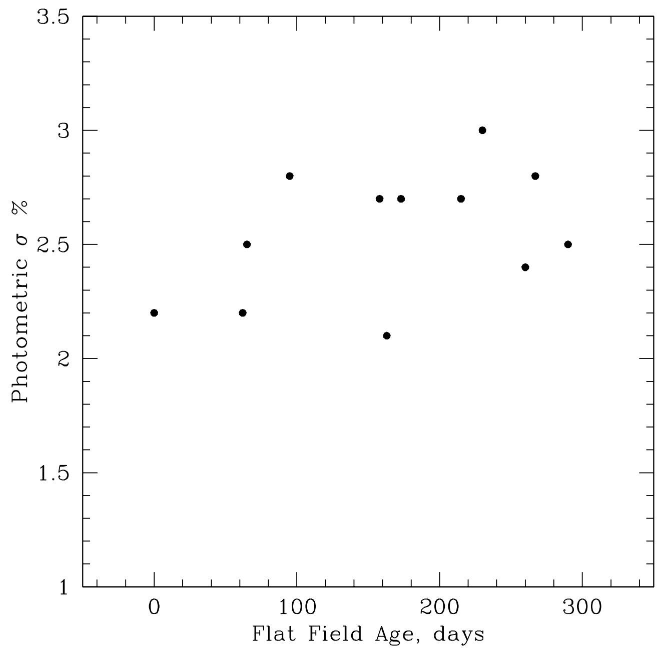

Figure 3.4: Stability of the Special Dome Flat images: accuracy of the photometry as a function of the flat field "age".

generated by this fit is normalized to one. Then, the flat is multiplied by this surface to create a corrected flat field.

Alternatively, one can think of this surface as a second flat field, and instead of correcting the dome flat, the user can divide the data by the regular dome flat and then by this surface. This surface is sometimes called an illumination correction. Without this correction the low frequency variability from edge to edge of the array is between 1 and 3 % depending on the filter, the objective and the type of flat used. After the illumination correction the low frequency variability improves to better than 1%.

Illumination Correction surfaces can be downloaded from the SOFI Web page. The observatory staff produces them typically once a month. Templates for observing a standard star in a array of 16 positions are available in the impex directory of SOFI on wsofi (in the calib directory: **SOFI_Illum_Correction_J**, **SOFI_Illum_Correction_H**, etc.).

NOTA BENE: The illumination correction frame refers **only** to the flat field that was used to create it, and it must not be used with other flat fields! The reason for this is that the illumination correction removes the effect of different dome screen illumination and in general every time the user obtains dome flats the intensity of the lamps is slightly different.

3.5.4 Arcs

Wavelength calibration can be done with the Xenon and Neon lamps in the adapter. The Xenon lamp has a better distribution of lines and is by itself sufficient to calibrate the wavelength scale of data taken with the low resolution grisms. Both the Neon and Xenon lamps should be used to calibrate the medium resolution grisms.

Arcs are taken with the template **SOFI_spec_cal_Arcs**. The parameters in this template are displayed in Table 3.13. In this template, one can enter a list of `DIT`s, `NDIT`s, grisms, slits and lamps.

If the number of exposures is greater that the number of elements in either of these lists, the list is repeated until the the correct number of exposures have been completed. The choices for the lamps are: Xe - Xenon, Ne - Neon, B - Both and N - None. The choices for the slit are: 0.6, 1 and 2. The choices for the spectral mode are: B and R for low resolution grisms, H and K for the high resolution grism. Although, the template enables one to do this, it is best to keep things simple, i.e. just takes arcs with one slit and if another slit is required, run the template again with that slit.

The Xenon lamp warms up quickly and produces high background level in the arcs, notably when calibrating the red grism. To minimize the background, the user may want to split the time when the lamp is on giving the lamp some time to cool. To do this, just decrease the number of exposures and repeat the OBs with a few minutes delay, as many times as the NEXP was reduced.

Parameter signature	Value
Exposure Name	Arc_Calibration
DIT LIST	2 2 2 2
NDIT LIST	5 5 5 5
Number of exposures	4
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Spectro Mode	B R
Slit List	1
Lamp List	N Xe N Ne

Table 3.13: Parameters in the SOFI_img_cal_Arcs template with commonly used values.

Nota Bene: Remember to take images with the lamps off, to remove the pattern due to dark/bias, scattered light and thermal background. This makes it easier to identify the weaker emission lines.

In general you should avoid taking arcs during the night since the high illumination levels of the strongest emission lines in the arc images may cause persistence problems. It is therefore advisable in such cases that you use the arcs in the morning after your run to do the wavelength calibration and then use the atmosphere to check the zero point of the calibration during the night. Both OH emission and sharp atmospheric absorption lines can be used. The P1 branch lines of OH are very good for wavelength calibration. Avoid the blended Q branch lines. Sample spectra for Xenon, Neon, and the main OH emission lines are displayed in appendix A.

Predefined OBs for wavelength calibration with the correct exposure times are available at the telescope.

3.6 Finer Points

Some of the information in this section is available through the manual but here it is concentrated for the convenience of the user.

3.6.1 Choosing `DIT`, `NDIT` and `NINT`

The appropriate value of `DIT` depends on the intensity of the source and the background. First and foremost, the `DIT` must be kept short enough that moderately bright objects of scientific interest do not saturate. On the other hand, in order to maximize the S/N ratio, one would like to work in background limited instrument performance, i.e. the sky intensity in a single frame should be sufficiently high that the sky shot noise will dominate over the detector read-out noise. In the K_s band, where the sky is bright, this can be reached with `DIT`s of one second. Through the spectroscopic modes, where the background is lower, longer `DIT`s are necessary. For most observations this will mean a `DIT` between 10 and 60 seconds.

In addition, shorter `DIT` means larger overheads because every `DIT` is associated with certain fixed overheads (i.e. for reset and read-out), and the shorter the `DIT`, the more `DIT`s it will take to complete the desired total integration time.

Once the `DIT` is chosen, the `NDIT` can be determined from the desired offsetting frequency. During good weather conditions one can stay on the object as long as ∼2 min for broad band imaging (∼5 min for narrow band imaging and ∼15 min for spectroscopy) before switching to the sky, and in this case `NDIT` = 2 min / `DIT` is appropriate. Note that in case of short `DIT`s the `NDIT` may have to be reduced further by a factor of 1.2-1.3 to take into account the overheads. If conditions are not so good, e.g. the sky intensity is fluctuating rapidly, or if one simply does not wish to integrate that long, then a lower value of `NDIT` can be used. As a general rule, the switching frequency should be higher for larger fields of view or longer wavelengths.

Another consideration that has to be taken into account in choosing the `NDIT` is the need to have a sufficiently high number of jittered images (1) to create a good sky image without stellar residuals, and (2) to remove well the array cosmetic defects and the cosmic rays (albeit there are few cosmic rays because of the short integrations for individual images in the IR). Three jittered images is the lowest meaningful number to ensure the array cosmetics removes well, but having 5-7 or more images is preferable, especially if they have to be used for creating a *sky* frame.

An additional restriction on the offsetting frequency applies to imaging observations. Unlike equatorial telescopes, the pupil plane of the NTT rotates relative to the image plane and, for reasons which may be due to internal reflections within the objectives, this causes pupil ghosts (images of the telescope support structure near the primary mirror) to appear in sky subtracted images. **In other words, the traces of the spider supporting the secondary mirror do not fully subtract on images taken more than 5-10 min apart**. The effect is greatest when the parallactic angle changes quickest and this occurs when the telescope is near the meridian. The effect is worst for images taken in K_s and the large field objective. To minimize this effect, the beam switching frequency should be such that the parallactic angle does not change by more than 0.5 degrees between exposures. For "jittered" images the residual effect is at or below the shot noise level when applying standard reduction techniques which involve running sky measurements over $\approx$ 10 frames. For applications requiring large object-sky offsets, it is advisable to use a strategy which automatically equalizes the parallactic angle of the two. This strategy can be employed in two SOFI templates: **SOFI_img_obs_AutoJitterOffset** and **SOFI_img_obs_JitterOffset** – just set the parameter `"rotate pupil"` to "true". It is possible to reduce the effect of the ghosts during the data reduction by running sky measurements over only 2-4 frames but this makes the data reduction somewhat more complicated.

Finally, in the spectroscopic mode only, one can accumulate a number of `NINT` exposures in one nodding position (A or B) before moving the telescope to other side of the nod. This feature allows to minimize the overheads for moving the telescope between the two nodding positions. These overheads are bigger than the ones related to the small jitter offsets.

3.6.2 Autoguiding

The NTT tracks very well over most of the sky. For IR imaging and some spectroscopic observations, the exposures are short enough that there is no need to guide. Guiding is necessary only for spectroscopy of faint targets, with exposures of 10-15 min or longer.

Observing Mode	Description
LARGE_FIELD_IMAGING	Imaging with the large field objective
LARGE_FIELD_SO_IMAGING	Imaging with the large field objective
SMALL_FIELD_IMAGING	Imaging with the small field objective
POLARIMETRY	Polarimetric mode
LONG_SLIT_RED	Long slit spectroscopy with the red grism
LONG_SLIT_BLUE	Long slit spectroscopy with the blue grism
LONG_SLIT_K	2.0-2.3 micron, long slit spectroscopy with the medium resolution grism
LONG_SLIT_H	1.5-1.8 micron, long slit spectroscopy with the medium resolution grism
DARK	Dark exposures
UNDEFINED	Undefined Mode

Table 3.14: The currently supported SOFI observing modes.

Nota Bene: If you choose to guide you should be aware that the guiding mode is currently fixed to *star2box* (as opposed to *box2star*) and this option has to be chosen in templates that allow to specify the guiding mode.

3.6.3 SOFI Observing Modes

For SOFI, there are several standard observing modes. For example, there are modes for wide field imaging and long slit spectroscopy. The observing mode defines which optical elements are inserted into the beam. As an example, in the large field imaging mode, the grism wheel is set to open, the mask wheel is set to the large field mask, and the objective wheel is set to the wide field objective. In addition, the collimator – used for focusing the instrument – is moved to a predefined position, depending on the mode and the filter. The standard modes available with SOFI are listed in the following Table 3.14.

3.6.4 Template Parameters - Signatures and Keywords

Template parameters can be described either by their signature, which are aimed at being self-explanatory, or by their keyword, which are more meaningful to the OS (Observing Software). When a template is created with P2PP, the signature form of the parameter is displayed. When the OB is passed to the BOB (Broker of Observing Blocks) for execution, signatures are translated into keywords. Although users will mostly be faced with signatures, they will later see the corresponding keywords, either when BOB is executing the template, or in the FITS image headers where some of these keywords are stored.

As an example, setting the filter on filter wheel 1 is done with the signature `"Filter wheel 1"`, whereas the corresponding keyword is `INS.FILT1.ID`.

3.6.5 File Naming and Exposure Number

The parameter "`Exposure Name`" determines the name the output files will be given on the instrument workstation. The raw data become available to the user under different names, consisting of an abbreviation of the instrument and a time stamp indicating the time the file was created, i.e. SOFI.2005-02-03T10:17:22.354.fits, where the time is UT. However, the exposure name is stored in the fits header and some users may find it convenient to use it in order to rename the files to somewhat more intuitive names for easier data reduction.

The exposure names consist of a base name, defined by the parameter "`Exposure Name`," plus an extension of the type _0003.fits. The extension is automatically set. If the base file name is found on disk, the sequential number is automatically incremented. For example, if there exists a file "fileName_0024.fits" on disk, the next file generated by the template is "fileName_0025.fits". If no file with the same base name is found on disk, the sequential number is automatically set to 0001 (see for an example Table 3.15).

NOTA BENE: Do not use spaces, slashes or other non-alphanumeric characters in file names and target names, otherwise the SOFI OS will report an error. However, the underscore symbol ("_") is acceptable.

Signature	Keyword	Default	Description	Input Value
`Exposure Name`	`DET EXP NAME`	–	Exposure Base filename	ngc1068
`Number of Exposures`	`SEQ NEXPO`	–	Number of exposures for	10
		–	the template	

Table 3.15: File naming signatures and keywords. The first filename will be ngc1068_0001.fits if no file with the "ngc1068" string was found on disk, and the last file will be ngc1068_0010.fits.

3.6.6 Detector Window

In all templates, **except acquisition templates**, it is possible to window the detector. The window is described with the coordinates of the origin and the window size (Table 3.16). Note that the entire array is read, the windowing parameters only determine which part of the image will be stored in the raw data file. Therefore, the windowing does not decrease appreciably the overheads.

Signature	Keyword	Default Value	Explanation
`Number of rows`	`DET WIN NX`	1024	Number of rows
`Number of columns`	`DET WIN NX`	1024	Number of columns
`First column of window`	`DET WIN STARTX`	1	First column of window
`First row of window`	`DET WIN STARTY`	1	First row of window

Table 3.16: Detector Window Signatures and Keywords.

Chapter 4

Phase 2 Preparation and Observing with SOFI

4.1 General Issues

Observations at the NTT are done under the normal ESO procedures. Observers are expected to arrive one to two days before their observations start and, with the help of the support astronomer, to fully specify their observations during this time.

Some hints:

- The visitors will be given a visitor account to use the computers in the visitors' office; there are possibilities to link a laptop to the local network.
- The visitors are expected to drive themselves around the observatory, so a **valid international driving license** is needed; if they can not drive, the observatory staff will drive them.
- The visitors are encouraged to call the La Silla safety number officer at 4444 in case of medical or other emergency, and to warn a member of the observatory staff for any outdoor activity; remember that **the closest hospital is a few hours away!**
- The visitors are expected to contact their support astronomer upon arriving; note that your support astronomer may be sleeping late if the previous night was dedicated to service mode observations or to technical work.
- The visitors are expected to read carefully the La Silla web page to acquaintance themselves with the rules of the operation of the observatory and the instrument they are going to use.
- The visitors should not edit by hand an OB or write a script to produce them, as it may cause crashes.

4.2 The VLT environment: P2PP, BOB, OS, TCS, DCS, ICS

Observations are described by observing blocks (OBs) – essentially scripts for driving the telescope and the instruments. The OBs consist of one or more templates – in effect, commands in the scripts. The templates have a number of parameters, much like the functions in computer programming.

A typical science OBs is made up of four components: a target, an acquisition template, an observation description, and a set of constraints. The observation description is itself made up of one or more observation and calibration templates. The constraints describe the acceptable conditions under which an observation can be carried out in service mode, and therefore the constraints section can be ignored by the visitor mode observers.

Templates are the simplest unit of observation. They are split into three categories: acquisition, observing and calibration. The templates are described fully in Appendix C.

The P2PP tool is a browser/editor that enables observers to create lists of targets and observing descriptions and then associate them with an acquisition template to form an OB. Your support astronomer will start you up on the P2PP, and will help you to optimize the observations but **we highly recommend the users to read carefully the P2PP Users' Manual**, available the User Support Division (USD) web-page at: `http://www.eso.org/org/dmd/usg/`

Once the OBs are created, they can be stored either in the local cache which resides on the same machine where the OBs were created (~/p2pp-cache/ID#) or they can be exported as ASCII files. The exported format of the files allows to ftp them from one machine to another.

NOTA BENE: Under no circumstances edit the OBs by hand with a text editor or with scripts! The software is sensitive to the format of the OB and extra (or not enough) spaces/tabs often cause crashes!

In visitor mode, P2PP is used to select OBs for execution. Observing blocks are selected by highlighting them with the left mouse button in the P2PP window. Once the OB is selected, the instrument operator will transfer it to the BOB (Broker of Observing Blocks) where it will be executed.

Note that once an OB is transfered to BOB, any changes that the observer make to the OB in the P2PP have no effect on the observations, unless the OB is loaded into BOB again.

In general, the highlighting of the OBs selected for execution is all the observer needs to do. Some observer intervention may be required during the execution of an observing block. For example, the user may need to select the correct object to be put in the slit or to indicate an offset during the acquisition. Everything else is either automatic or it is done by the support staff of the observatory. The users are advised to use the available time for inspection of the raw data.

BOB is a very versatile tool. It can be used to display the contents of an OB, it can skip templates within an observing block, it can be used to pause at a template, and it even allows to edit the parameters of an OB (but only in the templates that have not been started yet). Thanks to this facility it is possible to fine tune the execution of an OB in real time. However, with this freedom comes the danger to make a mistake, especially during a long and stressful observing night. Therefore, we recommend to make changes within the P2PP and then to re-load the edited OB into BOB. This provides an extra layer of verification because the P2PP has some built-in tools for verification of the OBs.

BOB runs a Tcl script which sends commands to the OS (Observing Software) which then sends commands to the TCS (Telescope Control System), the DCS (Detector Control System) and the ICS (Instrument Control System). The status of the instrument is displayed in the OS GUI (Graphical User interface) and the obtained raw images are displayed on the RTD (Real Time Display). The results are also sent to the archive machine and the off-line workstation wg5off. This will be discussed in more detail later.

When creating OBs, it is useful to keep them as simple as possible. Do not create complex OBs which switch from one mode to another. OBs with multiple science templates with different filters, imaging the same target are acceptable.

4.3 Arriving at the Telescope.

The NTT is run by a section of the joint control room (the "Ritz"). Consult the map on the La Silla web-page to find out where it is located. Please be aware that you will be sharing the "Ritz" with the observers at two other telescopes and some understanding and patience may be required.

When you arrive at the "Ritz", you will be confronted by a vast number of terminals. Most of these are of no concern to you. You will be primarily interested in the terminals at the right end of the room NTT section. Starting from right to left there is an empty table with a network connection that can be used to plug-in a laptop. The first desktop computer next to it is *wg5off*, where you can run *IRAF*, *MIDAS*, *eclipse*, *IDL*, web-browsers and other useful programs. This is a dual monitor machine. From here you can access and examine your data. Note that the system clocks of these computers are set to the UT.

To the left of the *wg5off* is the terminal *wh5dhs* where you run the P2PP. Immediately to the left of *wg5dhs* is a sequence of three vertically placed dual screen terminal for the SUSI2, EMMI, and SOFI workstations (in this order). The bottom screens show their OSs, BOBs, etc., while the upper screens show their RTDs. For convenience we can run some applications on the screens of the instruments that are not in use at the moment. To the left of the SOFI workstation are the computers of the telescope. The user will have no interaction with them.

When you arrive at the telescope, the entire system will have been started for you by the daytime operator. During the entire night you will have a telescope/instrument operator (TIO). It is important to emphasize that the telescope/instrument operator will be the one controlling BOB and SOFI. You as an observer will be selecting OBs for execution via P2PP and inspecting the incoming data.

NOTA BENE: The TIO is responsible for the operation and safety of the telescope and instrument; he has the authority to refuse an action that would jeopardize this safety, this include closing the telescope in case of dangerous weather conditions.

On the terminal, *wg5off*, do the following:

- The machine will be started by the support staff, together with all the necessary applications, so there is no need to log in.
- In a workspace of your choice you can start either an IRAF or MIDAS. Both reduction packages are supported. Your data is stored as FITS files in the directory */data/raw/YYYY-MM-DD/*, where *YYYY-MM-DD* is the date at the beginning of the observing night. We suggest that you do all your reductions in this directory.
- At the beginning of your first observing night fill in the **Data Backup Request Form** available from the La Silla web page. Note that you are requested to press the submit button twice: first after you have filled in the form, and the second time after you have verified the data. Based upon the information in this form the observatory staff will prepare a data package for you at the morning after your last observing night. It is important to fill in the correct postal address – we may need it in case we have to contact you, or mail you some data later. The data package includes only the raw data. Observers are responsible for saving their own reduced data. CD and DVD writers are available for this purpose.
- This machine runs the important *dataSuscriber* program, responsible for transferring the data from the instrument work station to the archive and to the off-line machine. Please make sure NOT to stop it!
- There is a number of quick-look data reductions tools, available on *wg5off*: for imaging and spectroscopic observations, for photometric calibration. Your support astronomer will introduce to them.

On the terminal *wg5dhs*, do the following:

- If required, login to this terminal as `visitor`. Your support astronomer will provide you with the password.
- In a workspace of your choice, click the left mouse button on the background window free area of the screen to start a terminal and from the prompt type "p2pp" to start the P2PP tool. Next, you will need to login with your username and password. They are the same as the ones you were given to login in the web-letter service, where you had found the notification for the approval of your program. If you do not have the userid and the password, ask your support astronomer.

You are now ready to observe, and even to obtain some calibrations before the beginning of your observations. You can use them to reduce the data during the night.

4.3.1 Image Analysis

The optics of the NTT are actively controlled, and to get the best out of the NTT, frequent correction to the primary are necessary. The telescope aberrations are determined by examining images of a guide star recorded through a Hartmann mask. The process is called image analysis. Its outcome is used to compute corrections to the optical configuration, which are applied as deformations to the primary mirror and as displacements of the secondary along three axis. Preferably, the image analysis should be done with the telescope pointing in the direction of your next target.

As most exposures in the IR are relatively short, the image analysis is done off line. Time spent doing image analysis is not spent on your source, thus image analysis should be used wisely. It usually takes 10 to 20 minutes to perform an image analysis and verify the result. Once, done the telescope will be at the correct focus. It is no longer necessary to check the focus after image analysis.

The image analysis is done by the TIO and the only action a visitor can take is to request an image analysis of the image quality is degrading. How frequently one does an image analysis depends on the required image quality. Here are some hints on how frequently it should be done.

i) If image quality needs to be better than 1.0", image analysis should be done if the altitude changes by 20 degrees (some times 30 degree; trust the advice of the telescope operator). For long integrations, where the source is changing altitude, one should perform the image analysis at an altitude that is 20 degrees higher if the source is rising or 20 degrees lower if the source is setting. The analysis should be repeated once the altitude of the object differs from the altitude where the previous image analysis was done by more than 20 degrees. In this way the object is never observed more that 10 degrees from the last image analysis.

ii) If the image quality is not critical, (this is usually the case for spectroscopic observations) then perform the image analysis once at the beginning of the night. It should be done with the telescope at an altitude where the bulk of the observations will be done.

iii) Good focus is very important. Poor focus can result in distorted images if any aberrations are present. In fact, distorted images are a good sign that either the telescope needs to be refocused or another image analysis needs to be done. The focus depends linearly with the temperature of the four serurriers. The coefficient is 0.079 mm of M2 movement per degree. In good seeing, a displacement in M2 of 0.03 mm induces a noticeable degradation in the image quality. So if the temperature has changed by 0.5 degrees or more since the last focus, one should refocus. On La Silla, the temperature changes quickest during the first hour of the night.

iv) During long integrations, greater that five minutes, it is possible to run the NTT in "closed loop" mode, that is, the optics are adjusted during the observations. For SOFI, integrations are usually shorter, and this is usually not needed.

NOTA BENE: The best way to find out if it is time for another image analysis is to monitor the image quality of the incoming raw data and to request an image analysis if you notice degradation! As a general guideline, however, you should trust the TiO's experience.

4.3.2 Focusing

The telescope and the instrument are focused separately. The instrument is focused automatically to a pre-defined collimator positions depending on the instrument configuration. This process is fully transparent to the user.

The telescope focusing can be done with a focus pyramid that produces five separate images. There is a specific template to do the focusing. Note that the image analysis normally corrects for the telescope focus (so the focus pyramid is used mostly for health check), and the only change of the focus that actually has to be done manually is the correction for the temperature of the primary mirror. All this is done by the TIO. The role of the visitor is to monitor the quality of the incoming raw data for any degradation.

4.4 The SOFI OS GUI Panel

The SOFI OS GUI panel (Figure 4.1) is used by the instrument operator to show the status of the instrument. It can also be used to setup the instrument, the detector, execute exposures and even point the telescope. A detailed description of this panel is given in the OS manual (VLT-MAN-ESO-14100-1510). In addition to the OS GUI panel, there are various panels related to ICS, DCS and IRACE and a large number panels that show the status of the instrument and the detector. These panels are not of direct interest to the observer.

We do not allow observers to use this panel to start exposures, as it is far more efficient and safer to observe with OBs running on BOB. Furthermore, data archiving, a fundamental requirement at the NTT and the VLT, is only possible if frames are accurately classified because the images taken via the OS panel have incomplete headers. The OS GUI is used only for trouble shooting.

4.5 RTD

The SOFI RTD (Real Time Display; Figure 4.2) is a versatile tool of frequent use. As the array is continuously read out, images are continuously displayed on the RTD. During acquisition or when the instrument is idle, the data is still taken (with the last used `DIT` and `NDIT`) but it is not written to disk.

A very useful feature of the RTD is the ability to store a frame into memory buffer and to subtract that frame from incoming frames. In effect, this feature allows a simple sky subtraction. This is essential for recognizing faint objects on backgrounds with significant structure. The stored frame is called a "fixed pattern" and to activate this feature, first click on the button labeled `Store Fixed Pattern` on the RTD screen and the current image will be stored. Next, click on `ON/OFF....` to subtract the stored images from the following ones. You'll probably have to click on the button labeled `Auto Cuts` or edit the cut levels directly to see the image. Clicking on `Store Fixed Pattern` again will load a new fixed pattern.

Naturally, it is best to store a fixed pattern before the telescope is centered on your science target.

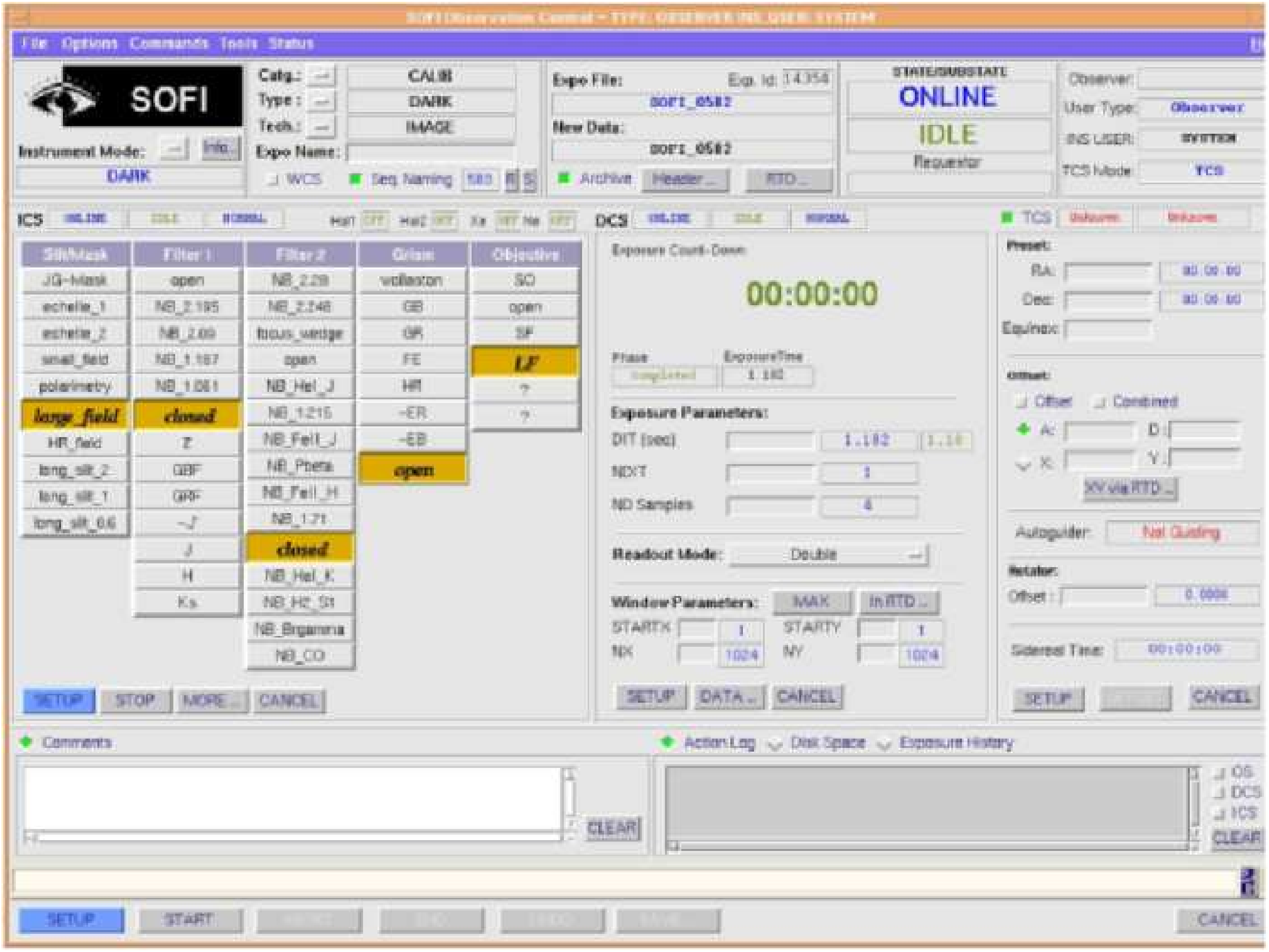

Figure 4.1: OS of SOFI

Acquisition templates "Move to ..." take an image off the target at a offset position defined by the user in the template. To expedite the process, one can even store a fixed pattern during the movement of the telescope (first make sure the `DIT` and `NDIT` have been updated to the values in the acquisition template!) but this may lead to dark/negative lines instead of dots on the subtracted image.

The RTD can display either each individual frame or it can display the average of `NDIT` frames (`INT` mode). The option is selected from the button labeled `DIT` or `INT`, respectively. The RTD can also display the image zoomed or reduced by an integer factor: clicking on the button to the right of label "Scale" will rise a pop-up menu with the available options.

The menus on the top left hand corner of the RTD can be used to activate sub-windows with various tool, which the observer may find useful:

- The `pick object` sub-window can determine the centroid and FWHM of selected objects, in pixels. It is useful for monitoring of the image quality.
- The `statistics` sub-window can be used to display the statistics of a region that can be defined by the cursor. It is useful for checking if the counts in the core of an image is bellow

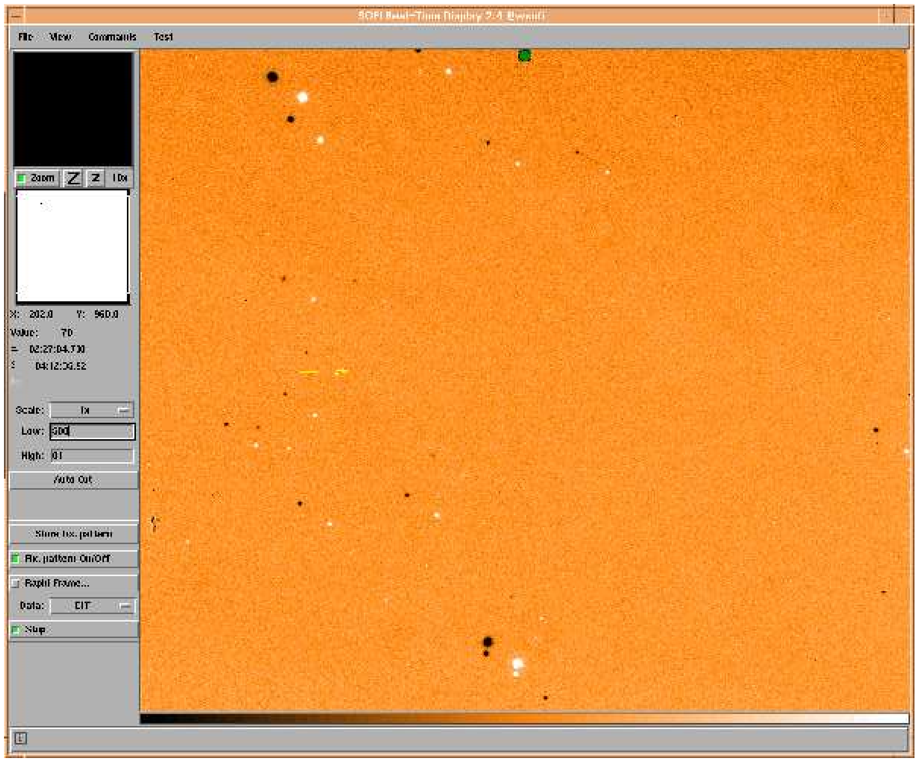

Figure 4.2: Real Time Display, with the "Store Fixed Pattern" option enabled. Note the offset between the negative and the positive star pattern. This offset is necessary to avoid self-cancellation of the objects in the field. The green dot on the top of the image flashes every time when the RTD updates the image. The yellow arrow is a remnant from a previous acquisition – it indicates the direction and the size of the offset that was carried out.

the non-linearity limit of 10,000 ADU.

- The `cuts` sub-window can be used to plot a trace that can be defined by the cursor, which is especially useful to check the count levels in spectra and the general background level. Zooming withing this sub-window is possible with the left mouse button, the right mouse button un-zooms.

Last but not least, the RTD display is also used with the acquisition templates to place objects of interest into slits in spectroscopic modes, into the clear portion of the polarimetric mask in polarimetric mode, or to specific position on the array in imaging mode. The interaction between the RTD and the acquisition templates is done by the TIO, after the user specifies his/hers requirements.

4.6 The Data Flow Path

The raw data passes from the detector to the IRACE controller where pre-processing of the data occurs. Exactly what the pre-processing does depends on the readout method. For example, in non-destructive readout mode the pre-processing involves fitting a line through the individual readouts and multiplying the slope by the `DIT`.

Next, the data is written to the disk of the instrument workstation *wsofi* as FITS files, and it is displayed on the RTD.

Finally, copies of the data are sent to the archive machine *wg5dhs*, and to the off-line computer *wg5off*.

During this transfer the file names are changed from "exposure name plus number" to "instrument name plus time stamp". The archival machine is used to produce the data package the user is given at noon after the last night of the observing run. The offline machine is where the user can access the data, in a directory */data/raw/YYYY-MM-DD/*.

The data transfer processes are transparent to the user.

4.6.1 Quick-Look Data Reduction Tools and Pipeline

It is foreseen to install a pipeline at the NTT in the future.

A new SofI VLT compliant pipeline is available at the NTT. In addition, the user is provided with number of tools for quick-look data reduction, based on the pipeline recipes, that allow rough data quality assessment. The main tools are:

- Imaging tool: it carries out cross talk removal, sky subtraction, flat fielding, alignment and combination of images specified in a list provided through Gasgano; observations with large offsets at clear *sky* fields are not reduced.
- Spectroscopic tool: it carries out sky subtraction, flat fielding, alignment and combination of the 2-dimensional spectra, and it subtracts and wavelength calibrates a 1-dimensional spectrum of the brightest object. Naturally, this tools works best for bright objects, the fainter the object, the higher the chance it will fail.
- Zero Point tool: cross talk removal, sky subtraction, flat fielding, simple aperture photometry. Note that the tool is sensitive to the position of the star on the array and if it is not centered within ∼20 arcsec it may fail to recognize the standard.

The SOFI web page contains the most recent instructions how to use the pipeline and the pipeline-derived tools. **The products from them are by no means science-grade!**

4.6.2 The Archive

All data taken at the NTT are archived into the ESO archive. For more retails see:
`http://archive.eso.org/`

4.6.3 The Calibration Plan

The calibration plan aims to ensure that all data stored in the archive can be fully calibrated, regardless of the specific needs of the program. Indeed, it is easy to imagine a situation that the data may be used later – after their proprietary period expires – from the archive for the purpose of another object. The calibration plan ensures that any limitations in that respect will not come from the lack of appropriate calibrations.

Therefore, daily calibrations are taken as a mater of routine, both by the observatory support staff and in Visitor mode runs by the observers wishing to calibrate their own data. The standard procedure is to run every morning after the end of the nigh time observations a special tool *calobBuilt* that inspects all files taken during the night and determines what calibrations are necessary. Furthermore, this tool prepares a calibration OB that can be loaded directly into BOB and executed.

However, Visitor mode observers are encouraged not to rely on our calibration plan to provide them with these data, but to take their own calibrations in the afternoons before their observations start.

This has a number of advantages: they would do their own quality control of the calibrations, and they will have at their disposal appropriate calibrations if they wish to reduce the data during the night.

The calibration plan includes:

- Imaging: special dome flats for all filters and imaging modes used.
- Spectroscopy: arcs and flats for each spectroscopic mode and slit combination.
- Polarimetry: flats.

4.7 At the End of the Night and at the End of Your Run

We will provide you with one set of CDs/DVDs/tapes (as requested in the *Data Backup Request Form* that the visitors **must** fill in at the beginning of their run) with all the **raw data** that were acquired during your run. If you need more than one set, you should make the copies yourself (we can provide blank media and we will help you to start with the copying).

If you want to save reduced data, you must do it yourself. In that case, you should save a copy of your data at the end of the night. Do not do it at the end of your run. It is common to generate over 2 Gb of data per night with SOFI! Leaving the back up until the end of the run mz mean that you could miss your plane! The raw data is stored in the directories */data/raw/YYYY-MM-DD/* on the machine *wg5off*.

At the end of your run you should fill out the *End of Mission Report*. This can be done via any web browser. You will find the form on the La Silla home page:

`http://www.ls.eso.org/lasilla/index.html`

and click on *End of Mission Report*.

Chapter 5

Data Reduction

This chapter does not aim to be the ultimate guide to reducing SOFI data but it does outline the general steps, it does provides useful tips and in effect it can be used as a mini-cook book. It represents the experience the NTT team has gained in reducing data from SOFI. This section of the manual will evolve with time and we are very keen to hear of any suggestions that people may have.

The first and the last principle of data reduction is to look at the data. The data do contain all answers you seek. We urge the users to experiment with differnet techniques, combination, and rejection algorithms, and to look at the quality of the final data product. We also warn the users, that pipelines, as good as they might be, are dangerous tools because they separate the observer from the data. Therefore, the products from any automatic data reduction tools must be treated with caution. First and foremost, one must understand the data: the specific instrumental effects, the stability of the weather conditions during the observations, etc.

5.1 Basic Concepts

Here we list some basic concepts for the SOFI data:

- There are two read out methods available with SOFI: NDR (non-destructive) and DCR (double-correlated). Data taken in one readout method should **NOT** be used to calibrate data taken in another (an exception are the spectroscopic arcs).
- The exposure time keyword represents the total integration time for a single image, i.e. `DIT`x`NDIT`. As the image you receive is the **average** of `NDIT` exposures of `DIT` seconds, the correct number to use for flux calibration is `DIT` and not the value given in the exposure time keyword.

5.2 Imaging

5.2.1 Inter-quadrant Row Cross Talk

This is the first step of the data reduction but some specific cases described bellow require post-processing of the final image to remove cross talk residuals.

A bright source imaged on the array produces a "ghost" that affects all the lines where the source is and all the corresponding lines in the other half of the detector. For instance, if the bright source is on row 300, the cross-talk affect the row $300+512=812$ and vice versa, if the source is on row 750, the other affected row will be $750-512=238$. The cross talk is seen either on high S/N data or if the bright source reaches near saturation level.

Though the effect is not completely understood it is well described and can be easily corrected. The intensity of the ghost is in fact 1.4×10^{-5} times the integrated flux of the line. An IRAF script for removing the cross talk is available from the SOFI web-page:
`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/reduction/sofi_scripts/`
The script has to be given input and output lists of images.

The script ca remove the cross talk only if the source that causes it is not saturated! In case of saturation, the counts of the source will be decreased by the non-linearity and the subtraction of the ghost will be incomplete. However, even in those cases the users can improve the data. The cross talk manifest itself on the final reduced image as: (i) residual of the ghost, and (ii) residual of the line leaks, i.e. horizontal lines with increased counts. While there is nothing one can do for the formen effect, short of masking, the latter one can be removed. This can be achieved in a few steps:

(i) block-average the image along the horizontal lines; note that the IRAF task *blkavg* is not well suited for this purpose because it does not allow to use median averaging or to impose rejection and lower threshold limits. Instead, it is better to use *imcombine* feeding it with a list that contains each row of the image as individual entry: final_image[1,*], final_image[2,*], final_image[3,*], etc. The use median averaging, suitable rejection algorithm and upper threshold to exclude from the averaging any sources. The result from this step will be a 1-dimensional vector-image.

(ii) expand the vector-image to the full size of the final image by replicating it; the IRAF task *blkrep* is well suited for this purpose. The result from this step is a 2-dimensional image with a size matching the size of the final image.

(iii) subtract the image produced in the previous step from the final image; ideally, this should remove the residuals from the horizontal lines. However, one should exercise caution because any imperfect flat fielding may affect the procedure, leaving artificial gradients across the image.

As explained above, in many cases the cross talk effect can not be removed completely, but sometimes the field of view can be rotated so the ghost image can be relocated to an area of the field away from the target. It is enough to relocate the bright source on a different raw or column than the target, and on a different raw than the one corresponding raw in the upper/lower half of the array.

5.2.2 Masking the Bad Pixels

The SOFI detector array suffers only minor cosmetic defects – it has ∼0.1% or ∼1000 bad pixels.

A mask of the bad pixels is available in the SOFI web page:

`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/reduction/bad_pix.html`

We consider the following types of bad pixels:

- Dead pixels : they are computed from the histograms of flats taken during SOFI Calibration Plan; the distribution of the pixels values is fitted with a Gaussian (mean, sigma), and we select the dead pixels as the ones whose value lays 4σ bellow the mean value.
- Hot pixels : they are computed from the histograms of darks taken during SOFI Calibration Plan; the distribution of the pixels values is fitted with a Gaussian (mean, sigma), and we select the hot pixels as the ones whose values lays 4σ above the mean value.
- Noisy Pixels : they are computed from the histograms of the sigma image obtained when averaging the flats and the darks of the previous 2 steps.
- Frame Pixels : the mask also marks as bad those pixels that are masked by the edges of the focal plane field mask.

NOTA BENE: The masking must occur before the images are shifted and aligned!

It is up to the user how to exclude the masked pixels. Perhaps, the simplest way is to use two masks. The first one will have zero values at the bad pixels and one at good ones. Every raw data frame has to be multiplied by this mask, ensuring that all bad pixels will have the same value. The second mask will have zero values at the good pixels and a large negative value, i.e. $-1e6$ at the bad values. This mask will have to be added to the row frames after the multiplication. It will set the bad pixels to a value outside the "good" pixel values for SOFI.

Of course, the fractional offset during the image alignment may move some of this artificial negative flux into the acceptable values but the large value makes sure that this will happen only rarely.

The final step of the application of the bad pixel mask is to set an appropriate lower threshold during the combination of the aligned images.

Indeed, some data reduction tools like IRAF has the capability to incorporate a bad pixel mask and the shifting of the images into the combination step. However, the *imcombine* task can carry out only integer shifts and this will degrade the spatial resolution of the image. This is the reason we recommend a 2-step shifting – fist with fractional offsets, and then with integer offsets (see Section 5.2.6). The only possibility to apply the bad pixel mask in this case is before any of the offsets, as described here.

5.2.3 Subtracting the Dark/Bias Frame

First and foremost, a SOFI dark frame changes with the `DIT`, so if a dark frame is subtracted from other frames, the `DIT` must be identical.

Secondly, the underlying bias pattern to any image is a function of the flux incident on the array, so it is not always useful to subtract separately the dark frame. In fact, the bias and the dark contributions to the total signal are almost impossible to separate without special efforts. In cases where the mean count level is low, for example narrow band images, the dark frame is a good approximation to the underlying bias pattern. In cases where the mean flux level is high, for example broad band images, the dark frame is a poor approximation to the underlying bias pattern, so subtracting it serves no real purpose.

Therefore, we suggest to avoid separate dark subtraction. Instead, the user can **subtract the darks together with the sky**, as described in the next section. The advantage of this approach is that the overall illumination is nearly constant, so the varying bias level problem mentioned above will be avoided.

The only case when the dark/bias subtraction is still necessary is the reduction of the flat field calibration images. See the description of the special procedure for that in Section 5.2.5.

5.2.4 Sky Subtraction

This is a critical operation, which depends on how many frames are available to create a *sky* image. The experience shows that at least 5-7 images are necessary to achieve acceptable sky subtraction, and this number depends strongly on the nature of the sky field: if the field is crowded with stars (i.e. the Galactic plane), this may not be enough. In such cases we recommend to make sure that at least 12-15 images at different locations are available. In general, the more frames you have, the better the results (but up to a point, because of such effects as pupil rotation and increasing overheads).

There are two basic strategies for sky subtraction:

(i) creating a single *sky* image, and then subtracting it from each individual frame. Here is a step-by-step description of the procedure to remove the sky from a stack of n jittered frames, where n is large.

(a) For each image, take the 10 images that were taken closest in time. These images will be used to estimate the sky. In case of jittered observations, when the target field is on all images, these 10 images will indeed include the target. In case of observations alternating between the *object* and the *sky* the list **must** include only the 10 closest *sky* images.

(b) Scale these 10 images to a common median. To first approximation, this is the *sky* image. However, it is possible to improve it. One possibility is simply to reject the most deviating values, i.e. rejection of the highest and the lowest 1 or 2 values, 3σ rejection, etc. We strongly encourage the user to experiment here. Another option is a more sophisticated 2-iteration rejection. After making a zero-order *sky* as described above, return to the list of the images you used to create this *sky*. From each of them subtract the *sky*. The result will be images with nearly zero background and only the stars above the background. Study the distribution of pixel values with image histograms and determine the border value between the background and the stars. Usually, the limit is ∼3 times the background standard deviation. Next, mask out the values above this limit. The easiest way to do it is just to replace the values above the chosen limit by a high or low value (i.e. 1e5 to −1e5) so when you combine the "masked" images to produce a second iteration *sky*, these pixels will remain out of the range of the "good" values used in the combination. The "good" values are usually defined as parameters of the combining task. Be careful before modifying the files with replacement. It is better to copy them into dummy files first!

(c) Scale the *sky* image to have the same median as the image from which it will be subtracted and then carry out the subtraction.

This method reduces the negative traces of stellar images on the sky-subtracted data.

The number of 10 images used to create the sky is somewhat arbitrary. It can be 5-7-... or even all available images.

(ii) subtracting from each image the average of the previous and the next image. In the more general case, the average (or the median) of the previous 2-3-... and the following 2-3-... images is subtracted. Strictly speaking, this is a specific case of the method described above. However, our experience shows that in most cases using only the two images nearest in time is sufficient.

The advantage of this technique is that it takes into account sky variation on time scale a few times `NDIT` x `DIT`. In the specific case of SOFI it also removes very well the pupil ghosts (usually observed as diagonal "stripes" in the South-East corner of the array) discussed earlier. Both these advantages are pronounced better if the number of images we use to subtract the sky is kept small - ideally, just the preceding the the succeeding images. While the reason for this is obvious for sky variations, it is not the case with the pupil ghost until one remembers that the pupil rotates and the ghost moves across the field of view. Therefore, it is best to sky-subtract using images that have the ghost nearly at the same position as on the target image.

The problem with this method is that some negative residuals from stellar images will remain on the sky-subtracted images. Indeed, with only the preceding and the succeeding images to subtract the sky, it is impossible to remove the "negative stars". This difference with the previous method makes us to consider it separately. Note that the "negative stars" can be dealt with later, on the stage of combining the shifted object images. Given enough object images and sufficiently low crowding, this technique works well.

This method is applicable for observations taken in both simple jittering more, and with offsets on a clear *sky* region.

A special attention is required to observations obtained following the schemes described in Section 3.2.5. As pointed there, the sky sampling in those observing strategies is somewhat rarefied and the user should check the residuals from the sky subtraction.

In case of observations in which the target has been kept on the array during every image, the user should mask the target out before constructing a sky image. This can be done in many ways, perhaps the most straightforward solution is to follow the same procedure as for masking out the bad pixels. In the case of 4-point observations described in Section 3.2.5 you have to create four pairs of masks: one with zeros in the target quadrant, and one everywhere else, and another, with a large negative value, i.e. $-1e6$, at the target quadrant, and zero everwhere else. Then every image has to be multiplied by that of the first masks that matches the location of the cluster, and summed with that of the second masks that again, matches the target quadrant. Remember to produce those manipulations on a copy of the original data. Finally, a suitable low threshold in *imcombine* will make sure that the target has been masked out from the sky.

An alternative to this masking is to use a "floating" sky, constructed from the six (in case of the 4-point scheme) images immediately preceding and succeeding every image. Those images have the target located on different locations than on the sky-subtracted image. As usual, the "global" average is preferable if the sky background is stable, and the "floating" sky subtraction is preferable if the sky varies.

NOTA BENE: The sky subtraction of every observation has to be considered individually! The recipes provided here refer to the most general cases. Every observation is different and covering all possibilities is out of the scope of this manual.

We provide some tools that help to carry out the sky subtraction. Check the *Data Reduction* section of the SOFI web page and ask your support astronomer for their latest version.

5.2.5 Flat Fields and Illumination Corrections

Creating a good flat field for SOFI data is difficult. The simplest way of creating flat fields is to subtract an image of the dome flat field screen with the dome lamp off from an image with the dome lamp on. This flat field has two short-comings. First, the shade pattern of the array is a function of the overall flux, so the shade pattern in the image with the lamp on is different from that in the image with the lamp off. Thus, the difference of the two will contain a residual shade pattern. Second, the illumination of the dome panel is slightly different from that of the sky. Furthermore, it changes with time because of the aging of the lamps used to illuminate the screen, and in the case of observations with $\lambda \geq 2.3$ micron, due to the variations of the dome temperature. Both these effects are at the 1-2% level and both can be removed.

The residual shade pattern can be removed if the **SOFI_img_cal_SpecialDomeFlat** template was used (see sec. 3.5.2). This template takes the usual sequence of images with the dome lamp on and off and, in addition, it takes the same set of images with the mask wheel vignetting the array (Figure 3.3). The vignetted part of the array is relatively free of scattered light, so it can be used to estimate and remove the shade pattern. However, this estimate of the shade pattern is valid for the frame that is vignetted and it is not valid for un-vignetted frame. The difference can be estimated from a region that is common to both the vignetted and un-vignetted frames. The method is outlined below.

(i) Collapse the following image sections along detector rows to form one dimensional images: columns 50 to 150 in the vignetted image, columns 500 to 600 in vignetted image and columns 500 to 600 in the un-vignetted image. For reference, call these images A, B and C, respectively.

(ii) The difference between the shade pattern in the vignetted and un-vignetted images is C-B.

(iii) The shade pattern in the un-vignetted frame is then A+(C-B) and this one dimensional image should be subtracted from the un-vignetted frame.

(iv) Steps (i) to (iii) should be done for the images with the lamp on and the images with the lamp off. Once the shading pattern is removed for both, one subtracts the image with lamp off from the image with the lamp on to form the flat field.

Small IRAF and MIDAS procedures performing these steps are available at the telescope and from the SOFI web page in the *Data Reduction* section, named special_flat.cl and midas_specialflat.prg, respectively.

The illumination corrections removes the difference between the illumination pattern of the dome flat screen and the sky. It is derived from a grid of 9-16 observations of a star (preferably a standard) across the field of view. The illumination correction is created by fitting a plane to the fluxes (not magnitudes!) of the star, after it has been flat fielded. Therefore, **each illumination correction surface refers to a particular special dome flat and it can not be used with another special dome flat!**

Special Dome Flats and Illumination Correction Surfaces for all broad band filters for Large Field mode are prepared by the observatory staff monthly. The latest versions can be downloaded from the Web Page of SOFI:

`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/reduction/flat_fielding.html`

A data base with older calibrations is maintained as well:

`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/images/fits/Archive/`

An IRAF script for producing Illumination Correction Surfaces – illumination.cl – is offered to the users. It can be downloaded from the SOFI web page:

`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/reduction/sofi_scripts/`

Twilight sky flats and flats created from the observations themselves can also be used to flat field the data. However, these frames suffer from the same problems as the uncorrected dome flats and, in the case of the shade pattern, it is not clear how they can be corrected.

Last but not least - the Special Dome Flats and the Illumination Correction Surfaces are mode and filter specific, i.e. they have to be prepared separately for each instrument mode and filter combination.

5.2.6 Image Alignment and Combination

Most data reduction package have tools for alignment of images and for their combination. For example in IRAF one can use *imexam*, *imalign* and/or *imcombine*. We refer the user to the corresponding user manuals.

Note that in case of IRAF, the task *imcombine* can not handle fractional offsets. The workaround is to use a 2-step shifting procedure. First, shift the images by the fractional part only with the task *imshift*. If you intend to do photometry on the final image, set the interpolation parameter of *imshift* to linear in order to conserve the flux during the shifting. In addition, set the boundary value that will be given to pixels with no value to constant, and set that constant to a large negative value, i.e. $-1e6$. Later, during the combination these pixels can be excluded with an appropriate lower cut-off threshold. If you use any of the outer options for the boundary pixels, you will end up "creating" data.

The second step of the shift can be carried with *imcombine*, using the offset facility of this task. The final image will have the largest possible dimensions, and the signal-to-noise ration will most likely degrade toward the edges because of the smaller and smaller number of images that cover the outer regions. Remember to set the lower threshold of *imcombine* appropriately, to exclude both the marked bad pixels and the pixels that were given bogus values at the edges of the shifted images.

5.3 Long Slit Spectroscopy

5.3.1 Inter-quadrant Row Cross Talk

This step is a **must** for reducing spectroscopic observations because unlike the imaging, the spectra are always aligned along the array columns, so a ghost of the upper half of the spectrum always appears in the lower one, and vice versa, unlike the imaging when the observers may be fortunate not to have bright star ghosts on top of their targets (or they can even rotate the instrument to avoid it). The effect is particularly dangerous when one looks for emission lines because their ghosts are emission line like and can be confusing.

More details on the cross talk can be found in Section 5.3.1.

5.3.2 Sky Subtraction

In most cases, the user simply has to subtract one image from another. This should remove most of the night sky emission. The subtraction of the average of every preceding and succeeding image works particularly well. The residuals can be removed during the extraction of 1-dimensional spectrum.

The tool for sky subtracting of imaging data works for the spectroscopy as well.

5.3.3 Flat Fields

Spectroscopic flats are taken with the dome flat field screen. Like imaging flats, one subtracts an image with the dome lamp off from an image with the dome lamp on. These flats also suffer from the shortcoming that the shade pattern is not perfectly removed.

However, the slits do not cover the entire chip; there is a region of approximately 50 pixels wide which is free of direct illumination and it may be possible to use this region to estimate the residual shade pattern and to correct the flat.

5.3.4 Removing Slit Curvature

Spectra taken with all SOFI grisms show slit curvature. For the red and blue grisms, the curvature amounts to a few pixels from the middle of the slit to the edge, and is well fitted with a quadratic. For point source observations, removing the slit curvature is an unnecessary step. However, extended objects may require to correct it in order to avoid degradation of the spectral resolution.

The correction is done by doing a 2-dimensional wavelength solution to arc spectra and both MIDAS and IRAF have tasks to do this. For the red and blue grisms a quadratic in the slit direction and a cubic or quartic in the wavelength direction is adequate. There are no cross terms. An excellent description of the method and the IRAF tools to do it can be find in the cookbook *2D-Frutti Reductions with IRAF* by Mario Hamuy and Lisa Wells. The relevant section is cited verbatim as Appendix A in *A User's Guide to Reducing Slit Spectra with IRAF* by Phil Massey, Frank Valdes and Jeannette Barnes. These documents are available on the WWW but for user's convenience we have placed copies of them at:

`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/reduction/other_manuals/`

For the medium resolution grism, the slit curvature is larger. As yet, we have not tried to do a 2 dimensional wavelength solution to arc spectra taken with this grism.

5.3.5 Arcs

For the red and blue low resolution grisms, it is sufficient to use the Xenon lamp for wavelength calibration. For the medium resolution grism, both the Xenon and Neon lamps should be used.

The main Xenon and Neon lines are identified in Appendix A. For the medium resolution and red grisms, a cubic fit to calibrate the dispersion is adequate. For the blue grism, a quartic fit is better.

5.3.6 Removing of the Atmospheric Absorption Features and Flux Calibration

The IR spectra are dominated by atmospheric absorption features. To remove these features it is customary to observe a star with a featureless spectrum at a similar airmass to the that of the target. This star is called telluric standard. The reduction involves the following steps:

- the spectrum of the target has to be divided by the spectrum of the telluric standard. This will remove the atmospheric absorption because – presumably – it affects the same way both spectra.
- the science spectrum has to be multiplied by the true intrinsic spectrum of the standard. This will remove the artificial "emissions" features introduced to the target spectrum by the intrinsic absorptions in the spectrum of the standard.

Removing the atmospheric features is a critical operation. In general, the spectra of the atmospheric standard and the spectra of the science target will not have exactly the same wavelength scale. They may differ by as much as half a pixel. This could be caused by internal flexure within the instrument or by the science object and the standard being on different parts of the slit. Thus, before dividing the standard into the science target, one should use the atmospheric absorption features in both to realign the spectra. The IRAF task *telluric* may be useful for this.

The true intrinsic spectrum of the standard is usually not known with any great precision. As discussed in Section 3.4.3, usually the telluric standards are selected to be wither solar analog (because a good Solar spectrum is available) or early type stars (because their spectra are easier to model). The IR Solar spectrum is available from the National Solar Observatory ("An atlas of the solar spectrum in the infrared from 1850 to 9000 cm-1" Livingston W. & Wallace L. N.S.O., Technical Report #91-001, July 1991). A more detailed description how to use solar analogs as telluric standards and an IRAF-based tool can be obtained from Maiolino, Rieke & Rieke (1996, AJ, 111, 537; web-sites `http://www.arcetri.astro.it/ maiolino/solar/solar.html` and `http://nicmos2.as.arizona.edu/ marcia/solar/`). For an example how to treat early spectral type telluric standards, how to stellar models, and for an empirical library of spectra of early type stars refer to Hanson et al. (1996, ApJS, 107, 281).

Good empirical IR spectrophotometric standards are not available. The only remaining way to do flux calibration is to observe the science target in one or more broad band filters and to scale the spectrum so that it agrees with the broadband fluxes. This method can achieve an absolute calibration of 5-10%. For example of IR flux calibration in the more general case of extended objects see Ivanov et al. (2000, ApJ, 545, 190). See also the discussion on the flux calibration in Section 3.4.3.

5.3.7 Alignment and Combination

There are two general approaches to combining spectra:

(i) to combine 2-dimensional images after an appropriate geometric correction that will align the wavelength axis and straighten the spectra

(ii) to combine 1-dimensional spectra (usually after wavelength calibration) that were extracted from the 2-dimensional images.

Every one of these methods has certain advantages and disadvantages, and the user will have to decide what is the best way to reduce the data. Obviously, the first method is easier for reducing extended objects because it will become trivial to extract spectra at different locations of these objects. However, the geometric correction involves heavy modification of the data, and some degradation of the resolution may be possible. The second method is easier to apply on point source spectra, and it has an added advantage of giving a straightforward estimate of the observational error - this is just the standard deviation obtained during the combination.

5.4 Polarimetry

As in the case of imaging, you should start to use a bad pixel mask that you can retrieve from:

`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/reduction/bad_pix.html`.

Then, you have to apply the flat field to correct for the pixel-to-pixel sensitivity variations across the chip. The flat field exposures should be performed using the same filter as the object exposures and the Wollaston prism in the optical path. Since the whole instrument rotates in order to provide a certain orientation of the Wollaston prism, separate exposures at different orientations are not required. We recommend to take dome flats, because when a sky map is used, some ghosts of the object on consecutive images may result in a wrong flat-field, especially at the position(s) of the object. Exposures with the lamp OFF and with the lamp ON must be combined to obtain the final flat field:

$$\text{FF} = (\text{lamp\_ON\_a - lamp\_OFF\_a}) + (\text{lamp\_ON\_b - lamp\_OFF\_b})$$

The final flat field is polarized, i.e. the median value of the upper field is different from the median value of the lower field. However, this problem can be overcome by an independent normalization of the flat field in each field. A further artificial polarization is introduced due to the deviation of the transmission ratio of the Wollaston prism (ideal: 50%:50% = intensity upper:lower beam). Three alternatives for the correction of the wrong transmission ratio are proposed (to see them in detail, please read the technical report available in `http://www.ls.eso.org/lasilla/sciops/ntt/sofi/`):

- Use the transmission ratios between the two beams of the Wollaston: of $C_{K_s} = 0.968$ and $C_J = 0.954$, respectively for K_s and J. Ratios for the other filters have not been determined as of yet.
- Since the sky is also affected by this effect, a good measure for the intensity ratio of both beams can be derived from the median of the lower/upper image. This method may not be applicable if the polarized object covers a large fraction of the lower/upper image (because in this case the median value may be influenced by possibly polarized object) and moreover, this method only works properly if the background radiation of the sky is unpolarized so the images are not affected by scattered moonlight.
- Fitting a $cos(2\theta)$ function to the intensity of the object on the image as a function of the orientation (θ) of the Wollaston prism (see Ageorges 2000, `http://www.eso.org/~nageorge/Pola/sofipola.html`).

The next step is the sky subtraction: since the intensity of the background radiation is an additive component to the intensity of the object, the subtraction of the sky will also result in the removal of the contribution of the sky polarization to the net polarization of the object. Therefore, the sky has to be estimated and subtracted independently for both the upper and the lower field.

Finally, the remaining instrumental polarization is expected to be mainly caused by the reflection on the tertiary mirror M3. It should therefore depend on the altitude angle of the telescope. However, the remaining instrument polarization was found to be $< 0.3\%$ for the K_s band, and $< 0.4\%$ for the J band (see Appendix B of the technical report for more details). Since the (statistical) error of the results from which these limits have been derived is in the same order of magnitude, a possible contribution by the mirror M3 could not be extracted.

If you pan to do polarimetric observations with SOFI we recommend to read carefully the three following reports:
`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/archive/pol/report.ps`
`http://www.ls.eso.org/lasilla/sciops/ntt/sofi/archive/pol/tech_rep_polarimetry.ps`
`http://www.eso.org/~nageorge/Pola/sofipola.html`

Please note that this is just a short description, consult the polarimetry reports from the SOFI web page for more details.

Appendix A

Calibration Arcs

The adapter contains both Xenon and Neon lamps. The Xenon lamp produces an even spread of lines for both the red and blue grisms. It is well suited for wavelength calibration. Figure A.1 show the main Xenon lines for the blue grism. There are two electronic ghosts, caused by the very bright lines near one micron, between 1.35 and 1.4 microns. Figure A.2 shows the main Xenon lines for the red grism. The continuum in the red is thermal emission from the lamp.

Both the Neon and Xenon lamps should be used to calibrate the medium resolution grism. Figures A.3, A.4, A.5 and A.6 show the main Xenon and Neon lines.

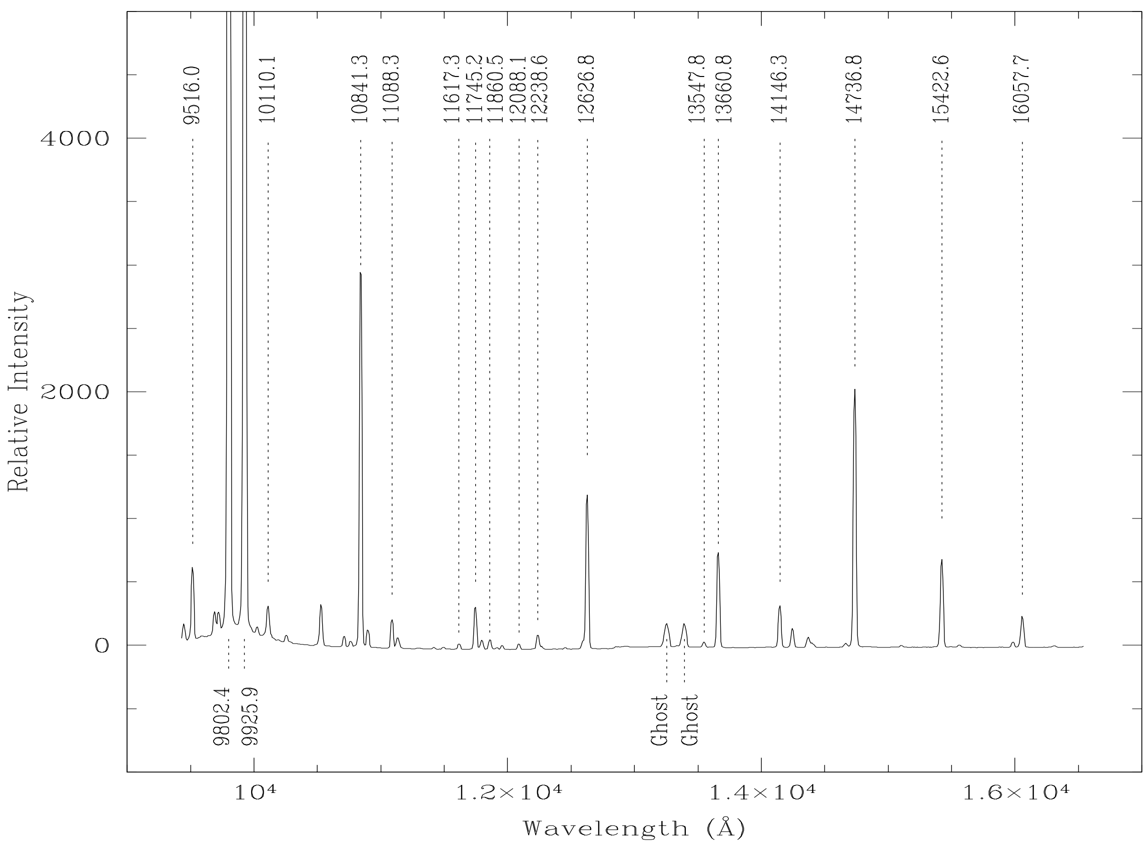

Figure A.1: A Xenon arc spectrum taken with the blue grism. The main lines are marked.

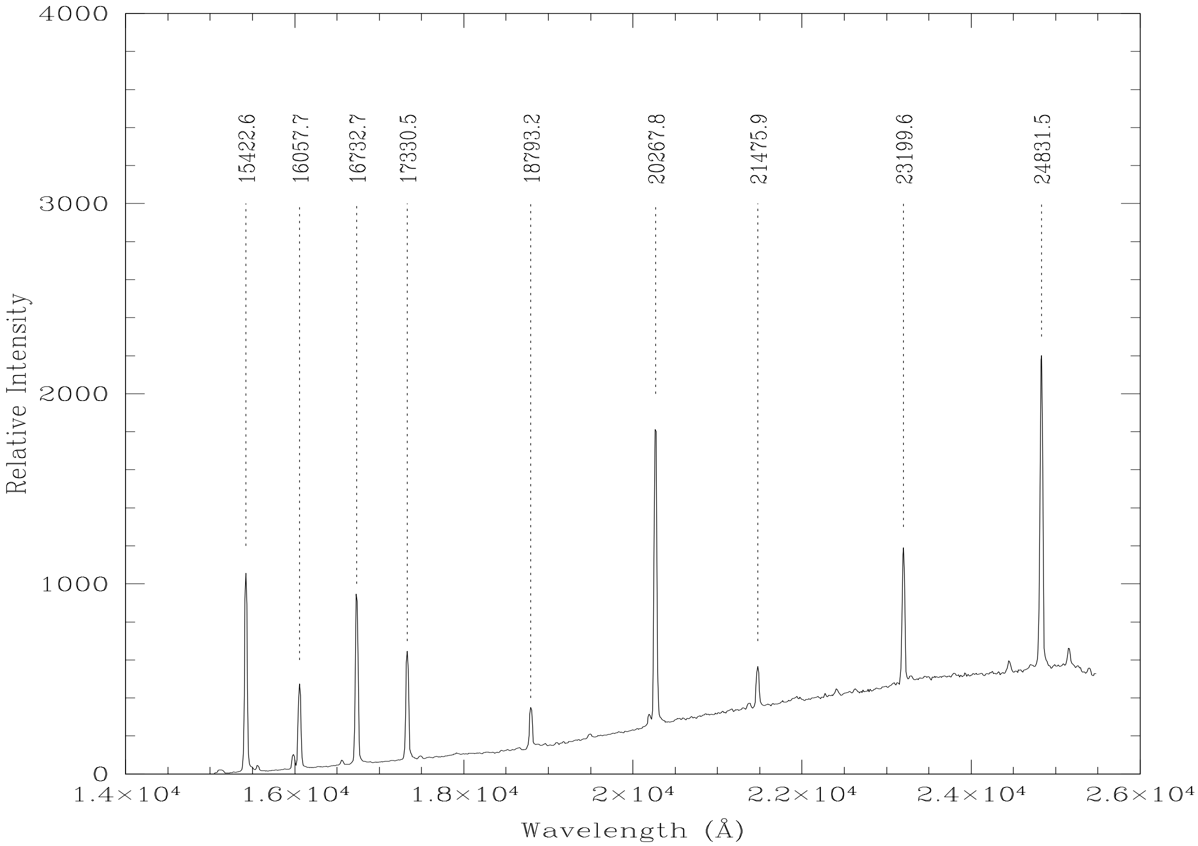

Figure A.2: A Xenon arc spectrum taken with the red grism. The main lines are marked.

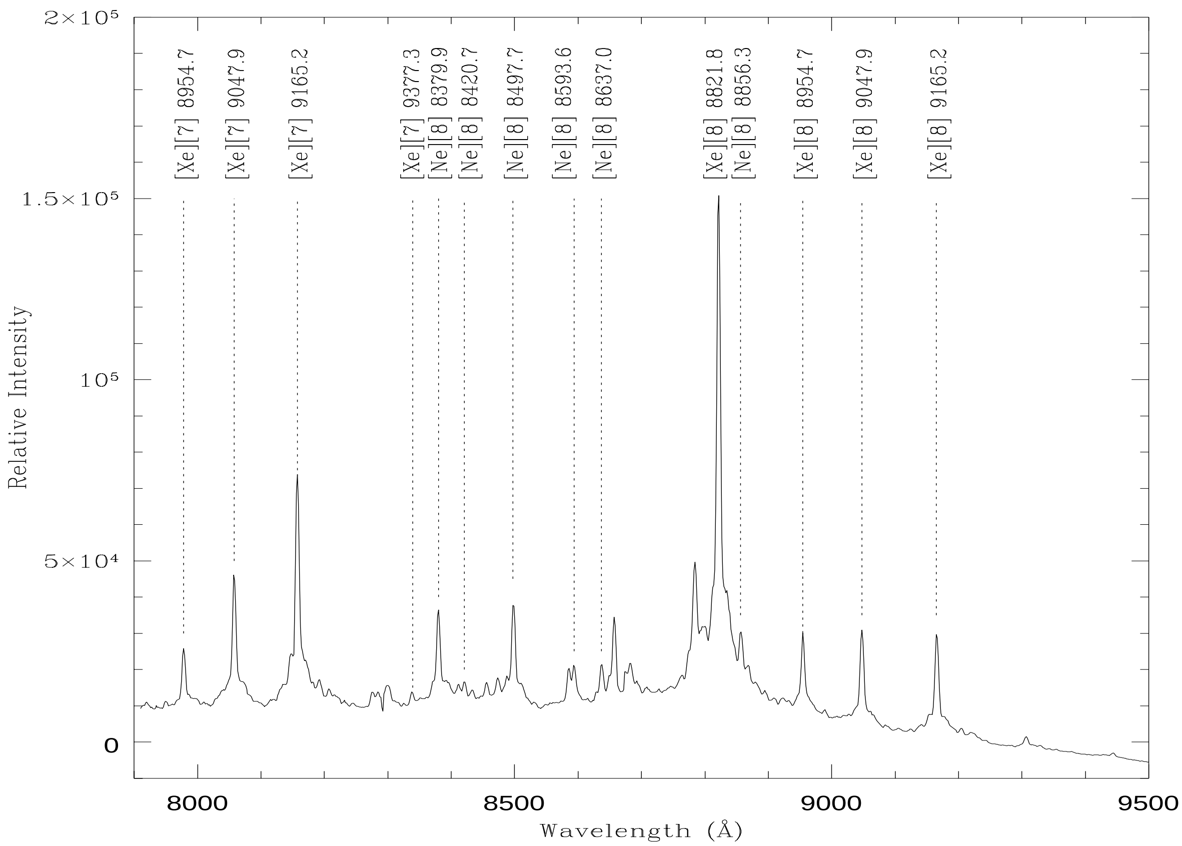

Figure A.3: A Xenon and Neon arc spectrum taken with the medium resolution grism at the Z atmospheric window. The main lines are marked.

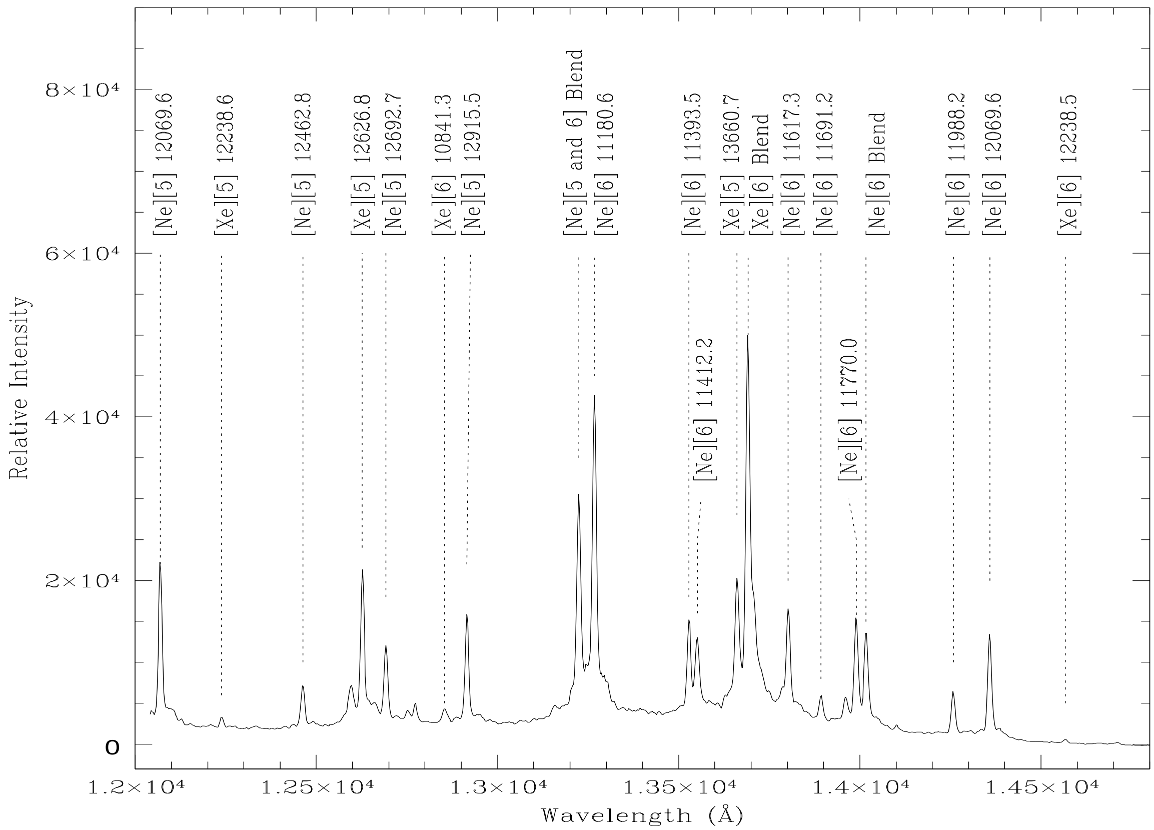

Figure A.4: A Xenon and Neon arc spectrum taken with the medium resolution grism at the J atmospheric window. The main lines are marked.

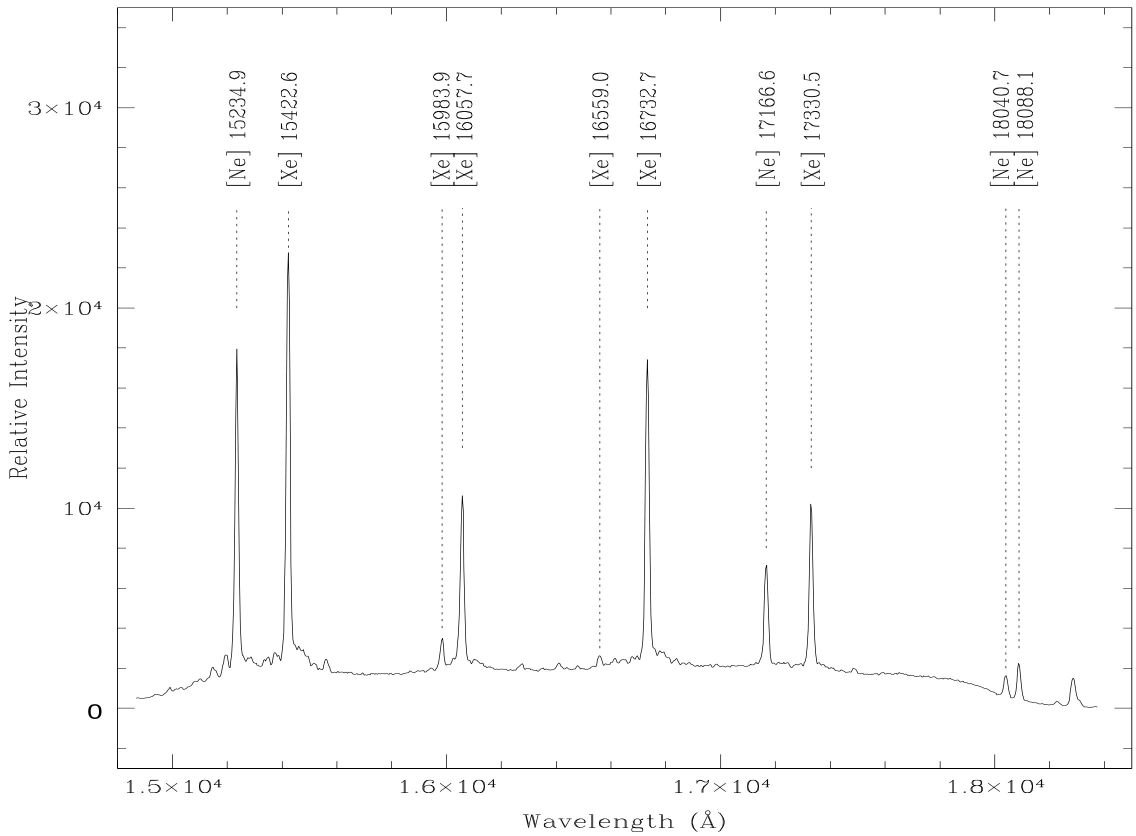

Figure A.5: A Xenon and Neon arc spectrum taken with the medium resolution grism at the H atmospheric window. The main lines are marked.

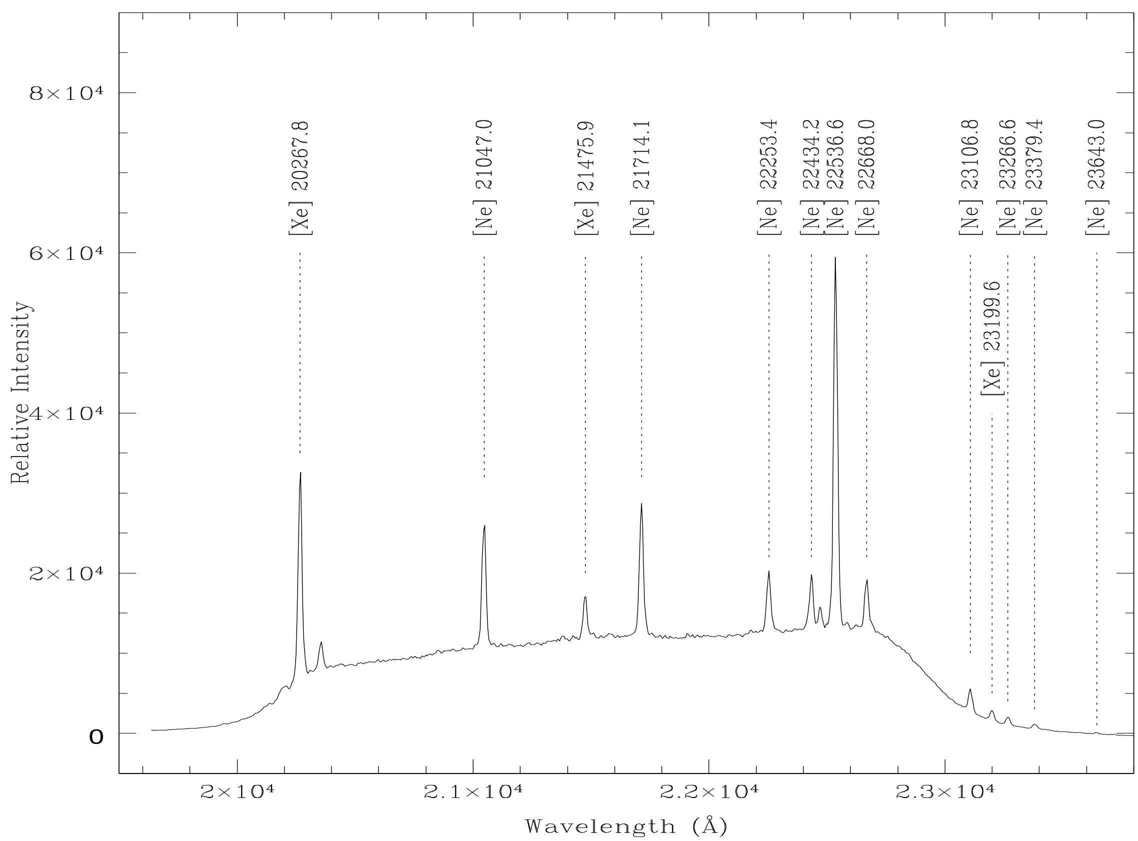

Figure A.6: A Xenon and Neon arc spectrum taken with the medium resolution grism at the K atmospheric window. The main lines are marked.

Appendix B

Atmospheric Absorption

In Figure B.1 the atmospheric transmission in the 0.8 to 2.5 micron region is plotted as a function of wavelength. Also plotted are the pass-bands for the SOFI filters.

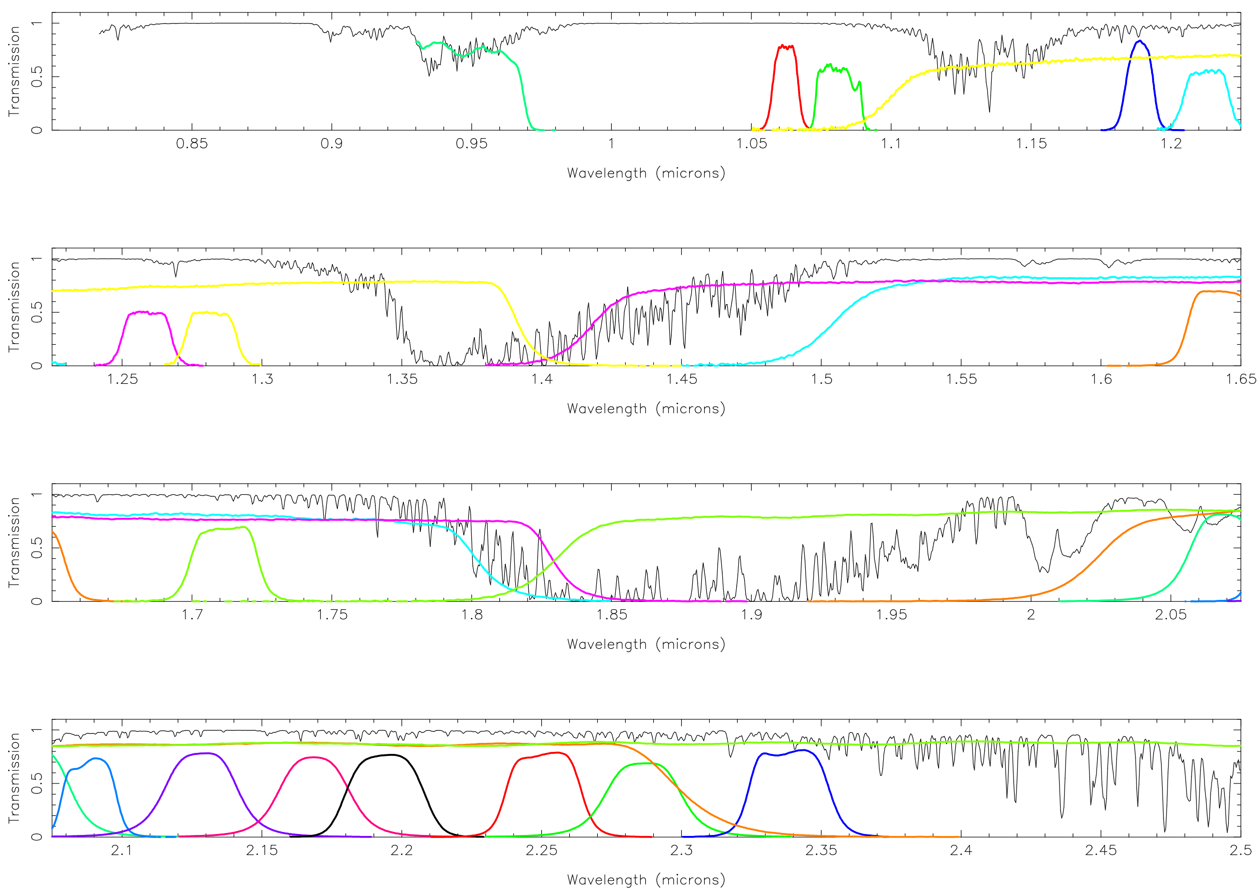

Figure B.1: The atmospheric transmission at a resolution of 8Å. Most of the SOFI filters plus some additional ones from ISAAC are marked.

Appendix C

SOFI Templates: A Reference Guide

C.1 General Points

This section provides a summary of the currently released SOFI templates. It assumes that the reader is already familiar with the capabilities of the instrument. Information about SOFI may be found on-line at the NTT Web site (http://www.ls.eso.org/). Note that undocumented and unreleased, prototype templates may be available at the telescope. Contact the SOFI support astronomer for further details.

SOFI has three types of templates: observation templates (OT) for science observations, Calibration templates (CT) for calibration exposures, and Acquisition templates (AT) for target acquisition. Tables C.1, C.2, C.3, and C.4 associates templates with observational scenarios.

Not all parameters have default values. In those cases where there is no default value, the value is "NODEFAULT".

IMPORTANT! For those parameters that require a string to be entered, for example the target name or the exposure name, spaces and special characters must NOT be used, only letters, numbers and "_" (underscore symbol) are allowed.

The SOFI templates are maintained by the SOFI instrument scientist and by the Science Operations team.

The following sections will review the SOFI templates in order of the instrument modes: imaging, spectroscopy, polarimetry.

This Appendix supersedes the SOFI Template Manual (ESO document LSO-MAN-ESO-40100-0007).

Type of Acquisition	Template(s) to use
Simple telescope preset (point and shoot)	SOFI_img_acq_Preset
Preset telescope and move an object onto a pixel	SOFI_img_acq_MoveToPixel
Preset telescope and center an object in a slit	SOFI_img_acq_MoveToSlit
Preset telescope and position an object for polarimetry	SOFI_img_acq_Polarimetry

Table C.1: Short guide for acquisition templates

Type of Imaging	Template(s) to use
Imaging of uncrowded fields or point-like objects	SOFI_img_obs_AutoJitter or SOFI_img_obs_Jitter
Imaging of crowded fields or extended objects	SOFI_img_obs_AutoJitterOffset or SOFI_img_obs_JitterOffset
Map of extended fields	SOFI_img_obs_AutoJitterArray or SOFI_img_obs_AutoJitterArray_1
Imaging requiring complex telescope offsets and/or guiding options	SOFI_img_obs_GenericImaging
Imaging Polarimetry	SOFI_img_obs_Polarimetry

Table C.2: Short guide for imaging and polarimetry templates

Type of Spectroscopy	Template(s) to use
Spectroscopy of point–like or moderately extended objects	SOFI_spec_obs_AutoNodOnSlit
As above but in Non Destructive read-out mode	SOFI_spec_obs_AutoNodNonDestr
Spectroscopy of extended objects (i.e. wider than ∼2 arc-minutes), or complex sequences of slit positions	SOFI_spec_obs_GenericSpectro
As above but in Non Destructive read-out mode	SOFI_spec_obs_GenSpecNonDestr

Table C.3: Short guide for spectroscopic templates

Type of calibration	Template(s) to use
Darks	SOFI_img_cal_Darks
Imaging Dome Flat Fields	SOFI_ima_cal_DomeFlats
Special Imaging Dome Flats	SOFI_ima_cal_SpecialDomeFlats
Standard Star (imaging)	SOFI_img_cal_StandardStar
Polarimetric Dome Flat Fields	SOFI_img_cal_PolarimDomeFlats
Arcs (spectroscopy)	SOFI_spec_cal_Arcs
Spectroscopic Dome Flats (for different readout modes)	SOFI_spec_cal_DomeFlats or SOFI_spec_cal_DomeFlatsNonDestr
Spectroscopic Adapter Flats	SOFI_spec_cal_Flats

Table C.4: Short guide for calibration templates

C.2 SOFI Imaging Templates

C.2.1 SOFI Imaging Acquisition Templates

Acquisition Templates determine how a target field is acquired by the telescope. In case of SofI some instrument parameters can be set up in the Acquisition Templates, such as the instrument mode. There are two acquisition template for simple imaging:

SOFI_img_acq_Preset

This acquisition template (Table C.5) does a simple telescope preset (i.e. pointing) in case of **imaging observations**, to the coordinates of the Target associated with the Observing Block. The Differential tracking rates can be set using `TEL.TARG.ADDVELALPHA` and `TEL.TARG.ADDVELDELTA`. There is no operator intervention, no acquisition image is saved on disk.

To save time, the instrument and detector parameters – most importantly the instrument mode and the filters – can be set to values that will be used in the first Observation Template attached with this Observing Block. An exception is the `NDIT` which should be set to 1, to save time, because even after the telescope points at the target, the next template will not start until the `NDITxDIT` integrations are completed.

It is the best template to use when pointing is not critical. The NTT typically points with an error of a few arc second. Most observers find this template sufficient for the purposes of their programs.

SOFI_img_acq_MoveToPixel

This acquisition template (Table C.6) has two parts. First, it presets the telescope to the coordinates of the Target associated with the Observation Block. Next, it requests the operator to interact with the RTD so that the user-specified object is moved to a user-specified location on the array.

In order for objects to be clearly seen, the telescope can do a small offset after the preset. The size and direction of the offset are template parameters (`TEL.TARG.OFFSETALPHA` and `TEL.TARG.OFFSETDELTA`). The operator is then prompted to store a fixed pattern that is subsequently subtracted from incoming images via the real-time display (RTD) features. After storing the fixed pattern, the telescope returns to the original position. At this point in time the operator is offered the possibility to change `DIT` and `NDIT`. This is useful if the target can not be identify securely because of the low signal-to-noise. If the operator changes the values, the telescope offsets again and the operator is required to store another fixed pattern before the telescope returns to the nominal position. This loop can continue until the operator has identified the target.

Parameter signature	Header Keyword	Value	Description
DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Add Velocity Alpha	TEL.TARG.ADDVELALPHA	0.0	Additional tracking velocity in RA (arcsec/sec)
Add Delta Velocity	TEL.TARG.ADDVELDELTA	0.0	Additional tracking velocity in DEC (arcsec/sec)
Rotation Offset on Sky	TEL.ROT.OFFANGLE	0.0	Rotation offset on the sky (degrees)

Table C.5: SOFI_img_acq_Preset.

Parameter signature	Header Keyword	Value	Description
DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Alpha Offset (arcsec)	TEL.TARG.OFFSETALPHA	0.0	Alpha Offset for sky subtraction (arcsec)
Delta Offset (arcsec)	TEL.TARG.OFFSETDELTA	0.0	Delta Offset for sky subtraction (arcsec)
Add Velocity Alpha	TEL.TARG.ADDVELALPHA	0.0	Additional tracking velocity in RA (arcsec/sec)
Add Delta Velocity	TEL.TARG.ADDVELDELTA	0.0	Additional tracking velocity in DEC (arcsec/sec)
Rotation Offset on Sky	TEL.ROT.OFFANGLE	0.0	Rotation offset on the sky (degrees)
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	False	T - guiding ON, F - guiding OFF
Preset Telescope ? (F/T)	SEQ.PRESET	True	T - full preset, F - fine-tunning of the pointing
Save Image ? (F/T)	SEQ.SAVE	False	T - preserve the acq. image, F - no

Table C.6: SOFI_img_acq_MoveToPixel.

To move the target from one position of the array to another, the operator simply draws an arrow on the screen with the left hand-side button of the mouse. At this point a window, which lists the pixel co-ordinates at the start and the end of the arrow, will appear. The operator can accept the offsets, cancel, or edit the co-ordinates directly. If the offsets are accepted, the telescope offsets by the desired amount. Finally, the operator is given the possibility to redraw the arrow for refining the position of the target if necessary. Once the operator is satisfied, the template finishes.

Guiding is possible (defaulted to the Telescope Control System's option *Star-To-Box*) **only** if `SEQ.COMBINED.OFFSET` is set to T and if guiding is on before the start of the template. The experience has shown that the guiding is necessary if the observer plans to stay at one pointing more than 15 min. This is rarely the case in imaging mode but can often happen in spectroscopic observations.

The `SEQ.PRESET` parameter allows the user to use the fine-tunning pointing functionality of the template without presetting the telescope. On other words, the user can improve the position of the target on the array, without full telescope preset. This option is particularly useful if acquisition was aborted for some reason or if multiple OBs to observe the same target are executed one after another.

The parameter `SEQ.SAVE` allows to save an acquisition image at the prize of some additional overhead for file transfer and saving.

The interactive pop-up windows are usually displayed before new images have arrived on the RTD. Therefore, operators are strongly advised to carefully check that a new image has arrived before clicking on these windows (e.g. for storing a fixed pattern, for changing the `DIT/NDIT` configuration). The arriving of a new image on the RTD is marked by a flashing green dot in the middle of the upper part of the RTD window.

C.2.2 SOFI Imaging Science Templates

SOFI_img_obs_AutoJitter

This observation template (Table C.7) offsets the telescope between exposures according to a random pattern of offsets automatically generated within the template. It is ideal for long integrations on "empty" fields or fields containing isolated point sources, and does not require a long list of offsets to be defined by the observer.

The offsets are distributed randomly within a box whose size is defined by `SEQ.JITTER.WIDTH` (in arc seconds), with the condition that the distance between any two points in a series of ten values is greater than certain minimum specified withing the template. This is intentionally done to ensure that the 5 frames before and after any frame are not too close spatially and can be safely used for creating a sky-image without large residuals for the sky subtraction.

By default, there is no telescope offset before the first exposure. If `SEQ.RETURN` is set to True (T), the telescope slews back to its original position at the end of the template; if not, the telescope is not moved. This feature is useful if more exposure of the same field are taken (i.e. with different filters) without running the corresponding acquisition template. In this case the parameters should be set to True.

If `SEQ.COMBINED.OFSET` is set to T and if guiding was started before the start of the template, guiding is *Star-To-Box*. Considering that in imaging mode the time between the offsets is limited typically to 1-3 min by the sky background variation, the guiding is rarely used in imaging mode.

The value of `SEQ.JITTER.WIDTH` corresponds to the full width of the box in which the offsets are generated. The choice of box size is a compromise between to constraints:

(1) Too wide a box may lead to insufficient image overlap. The signal-to-noise ratio will degrade toward the edged of the final combined image.

(2) Too small a value may lead to poor sky subtraction near extended objects, including bright stars with noticeable wings. Setting this parameter to zero is equivalent to staring the observations.

Consider the following example (Table C.8): the template will produce 6 fits files. Each image is jittered regarding to the previous one, and the jitter offsets are chosen randomly inside a box of 20 arcsec (`Jitter Box Width`) around the central position. Each of them corresponds to the average of 6 exposures (`NDIT`) of 10 sec (`DIT`). At the end of the exposures, the telescope moves back to the preset position (`Return to origin = True`).

SOFI_img_obs_AutoJtterOffset

This observation template (Table C.9) allows the user to move the telescope alternatively between the object and a nearby patches of sky. However, when pointing to the object, the position of the telescope is still randomly distributed within a box of size `SEQ.JITTER.WIDTH` (in arcsec).

The offset skies are at a constant distance (defined by `SEQ.SKYTHROW`, in arcsec) from the original telescope position, but at an angle randomly distributed between 0 and 360 degrees (i.e. the offset skies are distributed on a circle surrounding the initial telescope position).

By default, there is no telescope offset before the first exposure.

If `SEQ.RETURN` is set to True (T), the telescope slews back to its original position at the end of the template. If not, the telescope is not moved.

It is assumed that odd numbered exposures are on the object, and are consequently identified as SCIENCE frames. Even numbered exposures are assumed to be sky frames, and are consequently identified as OTHER.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Jitter Box Width (arcsec)	SEQ.JITTER.WIDTH	40	Jitter box size
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True

Table C.7: SOFI_img_obs_AutoJitter.

Parameter signature	Value
Exposure Name	NGC6118
DIT	10
NDIT	6
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	6
Filter wheel 1	K_S
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined offset ? (T/F)	F
Jitter Box Width (arcsec)	20
Return to origin ? (T/F)	T

Table C.8: SOFI_img_obs_AutoJitter. Example.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Jitter Box Width (arcsec)	SEQ.JITTER.WIDTH	40	Jitter box size
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
Sky Offset Throw (arcsec)	SEQ.SKYTHROW	300	Radius of the sky offsets region (arcsec)
Pupil Rotation	SEQ.ROTPUPIL	T	T - rotate, N - not rotate

Table C.9: SOFI_img_obs_AutoJtterOffset.

If the number of exposures is even, (`SEQ NEXPO`)/2 pairs of object/sky frames are produced. If the number of exposures is odd, then an extra frame is taken, and (`SEQ NEXPO` + 1)/2 pairs of object/sky frames are taken. Users are encouraged to give the parameter `SEQ.NEXPO` an even value.

Guiding is only possible for the object frames, if `SEQ.COMBINED.OFFSET` is set to True (T; must be done by the observed during the preparation of the Observing Block) and guiding is started before the template starts (done by the operator after warning from the observer. By default, there is no guiding for the sky frames.

This template can also be used to observe small extended objects by setting the throw small enough so that the object is always within the field of view. In such a case, however, `SEQ.ROTPUPIL` should be set to False (F).

Using this template with a jitter box size parameter `SEQ.JITTER.WIDTH` set to zero is equivalent to staring on the object.

For the pupil rotation see the discussion in Sec. 3.6.

Consider the following example (Table C.10): the sky is taken at 600 arcsec of the object, and a small jitter of 20 arcsec around the target is done. The number of exposures corresponds to the TOTAL number of exposures, that means SCIENCE exposures + SKY exposures. So here, you will have 5 images of your objects, and 5 images of the sky. Each image is the average of 10 (`NDIT`) exposures of 6 sec (`DIT`). No guiding is used.

SOFI_img_obs_Jitter

This observation template (Table C.11) allows the user to offset the telescope between exposures according to a list of predefined offsets (`SEQ.OFFSETALPHA.LIST` and `SEQ.OFFSETDELTA.LIST`), giving more freedom and flexibility. Complicated patterns can be used, pointing the telescope exactly on areas of interest. However, this comes to a price of more difficult preparation of the observation.

Parameter signature	Value
Exposure Name	NGC6118
DIT	6
NDIT	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	10
Filter wheel 1	K_S
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined offset ? (T/F)	F
Jitter Box Width (arcsec)	20
Return to origin ? (T/F)	T
Sky Offset Throw (arcsec)	600.
Rotate Pupil ?	T

Table C.10: SOFI_img_obs_AutoJitterOffset. Example.

The offsets in the list are **relative** to the previous position, they are in RA and DEC, and they are in arcsec. Note that the telescope offset are executed **before** the corresponding image is taken. In other words, if you want the first image to be at the position you have acquired the target, the first offset has to be (0,0).

If the number of the images is longer than the number of the offsets, the software loops back to the beginning of the list and executes again the first offset. If the number of the images is shorter than the number of the offsets, the software executes only as many offsets as necessary, starting from the beginning of the list.

The RA and DEC lists can have different length but this can be extremely confusing. It is good practice to use either lists with a single value or lists of equal length.

If `SEQ.COMBINED.OFSET` is set to True (must be done by the observer during the preparation of the Observing Block) and if guiding was started before the start of the template (will be done by the operator after a warning from the observer), the guiding is *Star-To-Box*. Given the short time spent on a single position – typically 2-3 min, determined by the sky level variations – guiding is usually rarely used.

If `SEQ.RETURN` is set to True (T), the telescope slews back to its original position at the end of the template. If not, the telescope is not moved.

Consider the following example (Table C.12): it gives to you 5 images at 5 different positions. Each image is the average of 3 (`NDIT`) exposures of 20 sec (`DIT`). The first image is taken at the position at which the target was acquired.

The following example (Table C.13) will produce 10 images, repeating the sequence of 5 offsets. Note that the sums of the offsets along RA and along Dec are non-zero, so the second offset pattern will be shifted relative to the first one by 2.5 arc to the East and 2.5 arcsec to the North.

This example illustrates an interesting usage of this template – to define a "closed loop" offset sequence that will bring the telescope at the original position (or close to the original position, i.e. 2-5 arcsec away, to imitate jittering, minimizing the effects of the array cosmetic defects). Therefore, these template can execute sequences of the type: target1-sky-target2-target1-sky-target2-..., saving from the time spent on the sky. Unlike some other templates such as the SOFI_img_obs_AutoJitterArray, the freedom to choose the offsets means that the targets and the sky can form an irregular pattern.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
RA offsets list (arcsec)	SEQ.OFFSETALPHA.LIST	NODEFAULT	list of offsets along RA
Dec offsets list (arcsec)	SEQ.OFFSETDELTA.LIST	NODEFAULT	list of offsets along Dec

Table C.11: SOFI_img_obs_Jitter.

Parameter signature	Value
Exposure Name	NGC6118
DIT	20
NDIT	3
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures	5
Filter wheel 1	J
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined offset ? (F/T)	T
Return to origin ? (T/F)	T
RA offset list (arcsec)	0 −50 0 100 0
DEC offset list (arcsec)	0 −50 100 0 −100

Table C.12: SOFI_img_obs_Jitter. Example.

Parameter signature	Value
Number of Exposures?	10
RA offset list (arcsec)	0. 5. −10. 2.5 5.
DEC offset list (arcsec)	0. 5. −10. 2.5 5.

Table C.13: SOFI_img_obs_Jitter. Offset Example.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
RA offsets list (arcsec)	SEQ.OFFSETALPHA.LIST	NODEFAULT	list of offsets along RA
Dec offsets list (arcsec)	SEQ.OFFSETDELTA.LIST	NODEFAULT	list of offsets along Dec
Pupil Rotation	SEQ.ROTPUPIL	T	T - rotate, N - not rotate

Table C.14: SOFI_img_obs_JitterOffset

SOFI_img_obs_JitterOffset

This observation template (Table C.14) is very similar to SOFI_img_obs_AutoJitterOffset. The only difference is that the user fully specifies the offsets in `SEQ.OFFSETALPHA.LIST` and `SEQ.OFFSETDELTA.LIST`, instead of executing randomly distributed offsets.

It is assumed that offsets are given so that the telescope alternates between object (odd numbered frames) and sky. The object frames are identified as SCIENCE, and the sky frames are identified as OTHER. The telescope offsets are executed before the taking the images.

Guiding is only possible for the object frames, if `SEQ.COMBINED.OFFSET` is set to True (T; must be done by the observed during the preparation of the Observing Block) and guiding is started before the template starts (done by the operator after warning from the observer.

Compare the following example (Table C.15) with the example for SOFI_img_obs_AutoJitterOffset template: the images are now taken in a user-defined sequence instead of in a random jittering pattern. The first offset (0,0) is executed before taking the first image, the second offset (5,5) is executed before taking the second image and so on. The number of exposures corresponds to the TOTAL number of exposures. Each image is the average of 10 (`NDIT`) exposures of 6 sec (`DIT`). No guiding is used.

SOFI_img_obs_AutoJitterArray and SOFI_img_obs_AutoJitterArray_1

These templates (Table C.16) are very similar to SOFI_img_obs_Jitter. They define a sequence of offsets in RA and DEC but in addition to that they allow to jitter randomly around each of the defined offset (array) positions. They are useful to build maps of large areas of the sky.

`SEQ.OFFSETALPHA.LIST` and `SEQ.OFFSETDELTA.LIST` are used to define the map (array) on the sky. The offsets between different positions are relative and they do not have to be equidistant (i.e. irregularly shaper maps/arrays are acceptable). If you have less offsets than number of exposures –

Parameter signature	Value
Exposure Name	NGC6118
DIT	6
NDIT	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	5
Filter wheel 1	Ks
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined offset ? (T/F)	F
Return to origin ? (T/F)	T
RA offset list (arcsec)	0. 5. −10. 2.5 5.
DEC offset list (arcsec)	0. 5. −10. 2.5 5.
Rotate Pupil ?	T

Table C.15: SOFI_img_obs_JitterOffset. Example.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
NJITT	SEQ.NJITT	1	Number of Jittered exposures around each Array position
Jitter Box Width (arcsec)	SEQ.JITTER.WIDTH	40	Jitter box size
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
RA offsets list (arcsec)	SEQ.OFFSETALPHA.LIST	NODEFAULT	list of offsets along RA
Dec offsets list (arcsec)	SEQ.OFFSETDELTA.LIST	NODEFAULT	list of offsets along Dec

Table C.16: SOFI_img_obs_AutoJitterArray and SOFI_img_obs_AutoJitterArray_1

Parameter signature	Value
Exposure Name	NGC6118
DIT	6
NDIT	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	4
NJITT	3
Jitter box width (arcsec)	20
Filter wheel 1	Ks
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined offset? (T/F)	F
Return to origin? (T/F)	T
RA offset list (arcsec)	50 0 50 0
Dec offset list (arcsec)	50 50 0 50

Table C.17: SOFI_img_obs_AutoJitterArray and SOFI_img_obs_AutoJitterArray_1. Example.

defined by the parameter `SEQ.NEXPO`, – BOB will start again with the first offset. It repeats simply the list of offsets you enter until it has the same number of exposures. It is possible to randomly jitter around each position of the map within a box whose size is set by `SEQ.JITTER.WIDTH`. The number of jittered frames at each offset (array) position is `SEQ.NJITT` and the telescope moves to the next map (array) position only after they are completed. The total number of frames acquired by this template will be the product of the number of array positions by the number of jitters around each one of them, i.e. `SEQ.NEXPO` x `SEQ.NJITT`.

A modified version of this template is called SOFI_img_obs_AutoJitterArray_1. It has identical parameter set, and it takes the same number of images as the original template but in a different order: exposures are taken at the positions of the array as defined by the offsets lists, then the random offset is applied and the entire array pattern is executed again. This template is preferable to the original one because it gives better sky subtraction. Also, if the weather conditions are poor (i.e. the sky background variations are strong, there are thin clouds, etc.), the entire mapped area is imaged under relatively more similar conditions in comparison with the SOFI_img_obs_AutoJitterArray template. On the other hand, if the conditions grow even worse and make it impossible to complete the mapping, the observer may be left with a shallow image over the entire area as opposed to a deep image of part of the mapped area. The observer must decide which strategy is better suited to the goals of the program before deciding which template to use.

Consider the following example (Table C.17): you will have 4 main positions defined in the RA and DEC offset lists. Around each of the offset position, you will have 3 images with jitter (inside a box of 20 arcsec defined by the parameter `Jitter Box Width`). In total this means 3 x 4 images = 12 images. Each of them is the average of 10 exposures (`NDIT`) of 6 sec (`DIT`), so the total exposure time is 10 x 6 x 3 x 4 = 12 min (without the overheads).

The template SOFI_img_obs_AutoJitterArray will take a sequence of 3 jittered images around the first offset position, then move to the next offset position and take 3 more jittered images and so on until the entire mapped region is covered. The template SOFI_img_obs_AutoJitterArray_1 will instead take one image at each 4 offset positions, then it will repeat the entire offset pattern `NJITT`=3 times, adding before each cycle a small jitter offset.

SOFI_img_obs_GenericImaging

This template (Table C.18) has some similarity with SOFI_img_obs_Jitter, but it allows the user to

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
List if NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
RA offsets list (arcsec)	SEQ.OFFSETALPHA.LIST	NODEFAULT	list of offsets along RA
Dec offsets list (arcsec)	SEQ.OFFSETDELTA.LIST	NODEFAULT	list of offsets along Dec
Obs Type (O or S)	SEQ.OBSTYPE.LIST	NODEFAULT	O - object, S - sky
Guiding (N B S)	SEQ GUIDING LIST	NODEFAULT	N - no guiding, B - Box-To-Star, S - Star-To-Box

Table C.18: SOFI_img_obs_GenericImaging

do any sequence of telescope offsets whether they be combined offsets (offsetting the telescope and the guide probe; necessary in case of observations with guiding) or non-combined offsets (offsetting the telescope alone; when guiding is not used, i.e. the telescope pointing changes on average at least once every 15 minutes). However, with this flexibility comes complexity. This is a complicated template and it is meant to be used in situations in which none of the other templates is suitable.

Telescope offsets and guiding options are defined as lists in `SEQ.OFFSETALPHA.LIST`, `SEQ.OFFSETDELTA.LIST` and `SEQ.GUIDING.LIST`. The offsets are relative to the previous position, they are in RA and DEC and they are in arcsec.

There are three guiding options: N, B or S. For option N, the offsets are non-combined. Option B stands for Box-To-Star but this option has been disabled and currently the default guiding mode is Star-To-Box. Please **always** use option S that stands for *Star-To-Box*.

Note: With large combined offsets, the guide probe may not be able to follow the one guide star. In such a case, the guiding system will automatically find another star, and resume guiding.

If any of the entries in `SEQ.GUIDING.LIST` are different from N, and if guiding is off at the beginning of the template, a pop up window prompts the operator to start guiding.

A list is also provided for `NDIT` (`SEQ.NDIT.LIST`), but not for `DIT`.

The observation type can be defined for each image, and is entered as a list in `SEQ.OBSTYPE.LIST`. O stands for Object and S stands for Sky. This is to make it essayer for the user to classify the images during the data reduction.

The total number of exposures is defined in `SEQ.NEXPO`. This number can differ from the number of elements in the aforementioned lists. Lists do not need to have the same length. If the number of exposures is larger than the number of elements in a list, the list is restarted from the beginning as many times as needed until the correct number of frames have been acquired. The lists can have any

Parameter signature	Value
Exposure Name	NGC6118
DIT	20
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	7
List of NDIT	3 2 3 2 3 2 3
Filter wheel 1	Ks
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Return to origin? (T/F)	T
RA offset list (arcsec)	0 −150 140 150 −140 −250 250
DEC offset list (arcsec)	0 −150 140 150 −140 −250 250
Obs Type (O or S)	O S O S O S O
Guiding (N B S)	S

Table C.19: SOFI_img_obs_GenericImaging. Example.

length; however having lists of different lengths can become extremely confusing. It is good practice to use either lists of one value, and/or lists of equal length.

At the end of the template, the telescope is returned to the original position, if `SEQ.RETURN` is set to True (T). If not, the telescope is not moved at the end of the template.

Consider the following example (Table C.19). It contains 7 offsets with the option to guide *Star-To-Box* (the only other option is *No Guiding*; *Box-To-Star* has been dsiabled). The object is always observed with a `NDIT` equal to 3, whereas the sky is always observed with `NDIT` equal to 2. At the end there are 4 images for the object, each of them is the average of 3 (`NDIT`) expositions of 20 sec (`DIT`). And 3 images of the sky, each of them is the average of 2 (`NDIT`) expositions of 20 sec (`DIT`).

C.2.3 SOFI Imaging Calibration Templates

SOFI_img_cal_Darks

This calibration template (Table C.20) produces dark frames, both for imaging and spectroscopy. The instrument is set to the DARK mode, where both filter wheels and the grism wheel are in the closed position.

The number of frames is defined in `SEQ.NEXPO`. Dark frames can be taken with different DIT and NDIT values, defined as lists in `SEQ.DIT.LIST` and `SEQ.NDIT.LIST`.

Note that `SEQ.DIT.LIST` and `SEQ.NDIT.LIST` do not need to have the same length. If the number of exposures is larger than the number of elements in a list, then the list is restarted from the beginning, as many times as needed until the correct number of frames have been acquired.

This template should be used to take dark frames at the end of the night for all the detector integration times that have been used during the night, though it is not strictly necessary since the dark signal will be removed along with the subtraction of the sky background.

SOFI_img_cal_DomeFlats and SOFI_img_cal_SpecialDomeFlats

Imaging dome flats are taken with these calibration template (Table C.21). For each element in `SEQ.DIT.LIST` and `SEQ.NDIT.LIST`, four images are taken: one with the dome lamp off, two with the dome lamp on and a fourth with the dome lamp off. The intensity of the dome lamp is controlled manually.

SOFI_img_cal_SpecialDomeFlats takes an additional set of images with the aperture wheel partially masking the array. These images are used to estimate the bias pattern. The reasons for using this template rather than the first are explained in the *SOFI Users manual*. The intensity of the dome lamp is controlled semi-automatically: the template maintains a database and once it is populated for a given configuration, the lamp intensities are taken from there.

The parameter sets for both templates are identical.

SOFI_img_cal_StandardSatr

This calibration template (Table C.22) is intended for standard star observations in one filter. If a standard has to be observed in a few different filters, this template has to be called as many times as necessary, with the appropriate filter defined in each template call.

The telescope can be offset to position the object at different positions on the array. **Note** that

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
List of DITs	SEQ.DIT.LIST	NODEFAULT	Detector Integration Time; individual exposure (sec)
List if NDIT	SEQ.NDIT.LIST	NODEFAULT	Number of DITs averaged into an individual image

Table C.20: SOFI_img_cal_Darks

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
List of DITs	SEQ.DIT.LIST	NODEFAULT	Detector Integration Time; individual exposure (sec)
List if NDIT	SEQ.NDIT.LIST	NODEFAULT	Number of DITs averaged into an individual image
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode

Table C.21: SOFI_img_cal_DomeFlats and SOFI_img_cal_SpecialDomeFlats.

unlike the other templates where the offsets are defined along the RA and Dec, here they are defined along detector rows and columns, and are entered into SEQ.OFFSETX.LIST and `SEQ.OFFSETY.LIST`. Offsets are in arcsec.

Guiding is possible (defaulted to *Star-To-Box*) if `SEQ.COMB.OFFSET` is set to True (T) and if guiding was started before the start of the template.

If `SEQ.RETURN` is set to True (T), the telescope slews back to its original position at the end of the template. If not, the telescope is not moved.

Although it is possible to observe standard stars with any of the imaging science templates, using this one is recommended because it sets up properly the header keywords necessary for the pipeline data reduction of the standards.

In the next example (Table C.23) SOFI_img_cal_StandardStar is used to obtain 5 images: the first on the acquisition position and the others defined by the list of offsets. At the end you have an "x" pattern.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Instrument Mode	INS.IMODE	NODEFAULT	Instrument Mode
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
X offsets list (arcsec)	SEQ.OFFSETX.LIST	NODEFAULT	list of offsets along rows
Y offsets list (arcsec)	SEQ.OFFSETY.LIST	NODEFAULT	list of offsets along columns

Table C.22: SOFI_img_cal_StandardSatr.

Parameter signature	Value
Exposure Name	S9104
DIT	2
NDIT	5
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	5
Filter Wheel 1	J
Filter wheel 2	open
Instrument mode	Large_field
Combined offset ? (F/T)	T
Return to origin ? (T/F)	T
X offset (arcsec)	0 45 −90 0 90
Y offset (arcsec)	0 45 0 −90 0

Table C.23: SOFI_ima_obs_StandardStar. Example.

C.3 SOFI Polarimetric Template:

C.3.1 SOFI Polarimetric Acquisition Template

SOFI_img_acq_Polarimetry

This acquisition template (Table C.24) is very similar to the SOFI_img_acq_MoveToPixel template. The polarimetric mask is displayed on the RTD and is superimposed on the image of the field. Then, the operator is prompted to define an offset by drawing an arrow on the RTD holding the left mouse button. The offset fine-positions the object into the transparent region of the mask.

Since the POLARIMETRY mode uses the large field objective, the instrument mode is not a parameter of the template.

C.3.2 SOFI Polarimetric Science Template

SOFI_img_obs_Polarimetry

This observation template (Table C.25) is used for polarimetry. It is quite simple, as it works as an imaging template.

The number of exposures must correspond to the number of the offsets, specified in `SEQ.OFFSETX.LIST` and `SEQ.OFFSETY.LIST`. **Note** that unlike most of the imaging templates, here the offsets are defined along detector rows and columns in arcsec, so that the users can move the object easily along the strips of the polarimetric mask.

Most importantly, the user have to decide which angle are necessary: one should observe the same object at several angles to determine the Stokes parameters (cf. section 2.4). All frames can be given an orientation relative to the previous position angle, by setting `SEQ.ROT.OFFANGLE` parameter (in degrees). When the template starts, the instrument is rotated on the sky by `SEQ.ROT.OFFANGLE`, and remains at this position until the end of the template. After the last exposure, the instrument is rotated back to the original position.

With this scheme, it is possible for the user to sample the object and the sky as desired for one rotator position, and then restart the template with another orientation on the sky for another series of exposures. At least two different orientations, separated by 45 degrees, are required for computing the Stokes parameters. This implies that **the template must be called at least twice within an Observation Block**, or with two different Observation Blocks, both with two different rotator positions. The most likely situation will be to set `SEQ.ROT.OFFANGLE` to 0 degrees in the first template, and then to 45 degrees in the second template.

Guiding is possible (defaulted to *Star-To-Box*) if `SEQ.COMBINED.OFSET` is set to T and if guiding was started before the start of the template. If `SEQ.RETURN` is set to True (T), the telescope slews back to its original position at the end of the template. If not, the telescope is not moved.

Note that the instrument mode is not a parameter of this template because all polarimetric observations are taken in Large Field mode.

This example (Table C.26) gives the typical values of the parameters. Note that to determine the Stokes parameters, the template will have to be executed twice with a rotator offset of 45 degree.

C.3.3 SOFI Polarimetric Calibration Template

SOFI_img_cal_PolarimDomeFlats

This template (Table C.27) takes polarimetric dome flats for a list of rotation angles.

Parameter signature	Header Keyword	Value	Description
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Alpha Offset (arcsec)	TEL.TARG.OFFSETALPHA	0.0	Alpha Offset for sky subtraction (arcsec)
Delta Offset (arcsec)	TEL.TARG.OFFSETDELTA	0.0	Delta Offset for sky subtraction (arcsec)
Add Velocity Alpha	TEL.TARG.ADDVELALPHA	0.0	Additional tracking velocity in RA (arcsec/sec)
Add Delta Velocity	TEL.TARG.ADDVELDELTA	0.0	Additional tracking velocity in DEC (arcsec/sec)
Rotation Offset on Sky	TEL.ROT.OFFANGLE	0.0	Rotation offset on the sky (degrees)
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	False	T - guiding ON, F - guiding OFF
Preset Telescope ? (F/T)	SEQ.PRESET	True	T - full preset, F - fine-tunning of the pointing
Save Image ? (F/T)	SEQ.SAVE	False	T - preserve the acq. image, F - no

Table C.24: SOFI_img_acq_Polarimetry.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures	SEQ.NEXPO	1	Number of exposures in the sequence
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	F	T - guiding ON, F - guiding OFF
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
X offsets list (arcsec)	SEQ.OFFSETX.LIST	NODEFAULT	list of offsets along rows
Y offsets list (arcsec)	SEQ.OFFSETY.LIST	NODEFAULT	list of offsets along columns
Rotator Offset ?	SEQ.ROT.OFFANGLE	45	Rotator offset (degrees)

Table C.25: SOFI_img_obs_Polarimetry.

Parameter signature	Value
Exposure Name	NGC6118
DIT	20
NDIT	3
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposures?	5
Filter wheel 1	Ks
Filter wheel 2	open
Instrument Mode	LARGE_FIELD_IMAGING
Combined offset ? (F/T)	T
Return to origin ? (T/F)	T
X offset list (arcsec)	0 −50 0 100 0
Y offset list (arcsec)	0 −50 100 0 −100
Rotator offset?	0

Table C.26: SOFI_img_obs_Polarimetry. Example.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DIT (individual exposure)	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
NDIT (number of DIT)	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures ?	SEQ.NEXPO	1	Number of exposures in the sequence
List of Rotator angles	SEQ.ROT.OFFANGLE	NODEFAULT	Rotator offset list (degrees)
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True

Table C.27: SOFI_img_cal_PolarimDomeFlats.

C.3.4 SOFI Spectroscopic Templates

C.3.5 SOFI Spectroscopic Acquisition Templates

SOFI_img_acq_MoveToSlit

This acquisition template (Table C.28) is very similar to the SOFI_img_acq_MoveToPixel template. The selected slit is drawn on the real-time display (RTD) superimposed on the image of the field. In most cases, operators will use the option to move the selected object to the center of the slit. Since each slit has a different position on the detector, the slit name (i.e. the 0.6, 1 or 2 arcsec slits) is explicitly stated in the template via the `INS.WHICHSLIT` parameter.

This acquisition has two parts. First, it presets the telescope to the coordinates of the Target associated with the Observation Block. Next, it takes and displays an image on the RTD. Finally, it requests the operator to interact with the RTD so that the user-specified object is moved to either a center of the slit, or to a user-specified location on the slit.

To make the target clearly visible, the telescope can do a small offset after the preset to obtain a "sky" image. The size and direction of the offset are template parameters (`TEL.TARG.OFFSETALPHA` and `TEL.TARG.OFFSETDELTA`). The operator is then prompted to store a fixed pattern that is subsequently subtracted from the incoming images via the real-time display (RTD) features. After storing the fixed pattern, the telescope returns to the original position. At this point in time the operator is offered the possibility to change `DIT` and `NDIT`. This is useful if the target can not be identify securely because of the low signal-to-noise. If the operator changes the values, the telescope offsets again and the operator is required to store another fixed pattern before the telescope returns to the nominal position. This loop can continue until the operator has identified the target.

To move the target from one position of the array to another, the operator has two options:

(1) If the target must be centered on the slit, one can use the build in feature by clicking on the "center" button on the RTD dialog box. The software will draw an arrow from the location of the selected object to the center of the slit and the operator will be asked to confirm the offset. This option is faster and it works well if the science observation is done via simple nodding along the slit.

(2) The operator can simply draw an arrow on the screen holding the left hand-side button of the mouse. At this point a window, which lists the pixel co-ordinates at the start and the end of the arrow, will appear. The operator can accept the offsets, cancel, or edit the co-ordinates manually. If the offsets are accepted, the telescope offsets by the desired amount. Finally, the operator is given the possibility to redraw the arrow for refining the position of the target if necessary. Once the operator is satisfied, the template finishes.

Nota Bene: There is no way of checking if the slit that is chosen in the Acquisition Template and the slit that will be used subsequently in the Observation Description Templates are the same. It is, therefore, of utmost importance that the astronomer ensures that they are the same.

Since the spectroscopic modes use the large field objective by default, the instrument mode is not a parameter of the template.

Guiding is possible (defaulted to the Telescope Control System's option *Star-To-Box*) **only** if `SEQ.COMBINED.OFFSET` is set to T (this must be done by the observed during the preparation of the Observing Block) and if guiding is on before the start of the science templates (this will be done by the operator after warning by the observer, before starting the execution of the Observing block). The experience has shown that the guiding is necessary if the observer plans to stay at one pointing more than 15 min. This is rarely the case in imaging mode but can often happen during spectroscopic observations.

The `SEQ.PRESET` parameter allows the observer to use the fine-tunning pointing functionality of the

Parameter signature	Header Keyword	Value	Description
DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Filter wheel 1	INS.FILT1.ID	NODEFAULT	Filter wheel 1 position
Filter wheel 2	INS.FILT2.ID	NODEFAULT	Filter wheel 2 position
Which Slit ?	INS.WHICHSLIT	NODEFAULT	Slit
Alpha Offset (arcsec)	TEL.TARG.OFFSETALPHA	0.0	Alpha Offset for sky subtraction (arcsec)
Delta Offset (arcsec)	TEL.TARG.OFFSETDELTA	0.0	Delta Offset for sky subtraction (arcsec)
Add Velocity Alpha	TEL.TARG.ADDVELALPHA	0.0	Additional tracking velocity in RA (arcsec/sec)
Add Delta Velocity	TEL.TARG.ADDVELDELTA	0.0	Additional tracking velocity in DEC (arcsec/sec)
Rotation Offset on Sky	TEL.ROT.OFFANGLE	0.0	Rotation offset on the sky (degrees)
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	False	T - guiding ON, F - guiding OFF
Preset Telescope ? (F/T)	SEQ.PRESET	True	T - full preset, F - fine-tunning of the pointing
Save Image ? (F/T)	SEQ.SAVE	False	T - preserve the acq. image, F - no

Table C.28: SOFI_img_acq_MoveToSlit.

template without presetting the telescope. In other words, the user can change the position of the target on the array, without full telescope preset. This option is particularly useful if acquisition was aborted for some reason or if multiple OBs to observe the same target are executed one after another. In this case, it is advisable to re-acquire the target with a false preset every 1-2 hours to ensure it has not drifted away from the slit.

The parameter `SEQ.SAVE` allows to save an acquisition image at the cost of small additional overhead for file transfer and saving.

The interactive pop-up windows are usually displayed before new images have arrived on the RTD. Therefore, operators are strongly advised to carefully check that a new image has arrived before clicking on these windows (e.g. for storing a fixed pattern, for changing the `DIT/NDIT`). The arriving of a new image on the RTD is marked by a flashing green dot in the middle of the upper part of the RTD window.

C.3.6 SOFI Spectroscopic Science Templates

SOFI_spec_obs_AutoNodOnSlit and SOFI_spec_obs_AutoNodNonDestr

These observation templates (Table C.29 and C.30) nod the telescope between two positions (A and B) along the slit. A cycle is a pair of two observations: AB or BA. Cycles are repeated in ABBA sequences. E.g. 3 cycles corresponds to an ABBAAB sequence, 4 cycles correspond to an ABBAABBA sequence, etc. Each observation consist of one or more exposures, as defined in the template by the `NINT` parameter. The total number of frames corresponds to `SEQ.NABCYCLES`×`SEQ.NINT`×2.

The mean amplitude of the nod is defined by `SEQ.NODTHROW` (in arcsec). The first exposure (A) is done after offsetting the object along the slit by −(`SEQ.NODTHROW`)/2 arcsec, which can be either negative or positive. The second exposure (B) is therefore +(`SEQ.NODTHROW`)/2 arcsec from the initial

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Spectro Mode	INS.SMODE	NODEFAULT	Spectroscopic Mode
Which Slit ?	INS WHICHSLIT	NODEFAULT	Which Slit
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	False	T - guiding ON, F - guiding OFF
Jitter Box Width (arcsec)	SEQ.JITTER.WIDTH	40	Jitter box size
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
Nod Throw (arcsec)	SEQ.NODTHROW	60	Nod throw (arcsec)
NINT	SEQ.NINT	1	Number of exposures in each A or B position
Number of AB or BA cycles ?	SEQ.NABCYCLES	1	Number of AB cycles

Table C.29: SOFI_spec_obs_AutoNodOnSlit.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
NSAMP	DET.NSAMP	4	Number of Samples
NSAMPPIX	DET.NSAMPIX	4	Sample Number per Reading
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Spectro Mode	INS.SMODE	NODEFAULT	Spectroscopic Mode
Which Slit ?	INS WHICHSLIT	NODEFAULT	Which Slit
Combined offset ? (F/T)	SEQ.COMBINED.OFFSET	False	T - guiding ON, F - guiding OFF
Jitter Box Width (arcsec)	SEQ.JITTER.WIDTH	40	Jitter box size
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
Nod Throw (arcsec)	SEQ.NODTHROW	60	Nod throw (arcsec)
NINT	SEQ.NINT	1	Number of exposures in each A or B position
Number of AB or BA cycles ?	SEQ.NABCYCLES	1	Number of AB cycles

Table C.30: SOFI_spec_obs_AutoNodNonDestr.

position along the slit.

In addition to nodding, random (typically small – a few tens of arcsec or smaller) offsets can be added in the middle of a cycle to locate the spectra at different positions on the array, improving the bad pixel removal and the flat fielding. A sequence of 4 cycles with jittering will result in the following sequence:

$$A(B+\epsilon_1)(B+\epsilon_1)(A+\epsilon_2)(A+\epsilon_2)(B+\epsilon_3)(B+\epsilon_3)(A+\epsilon_4)$$

where ϵ_N are the random jittering offsets. They are generated withing the interval defined by `SEQ.JITTER.WIDTH` (in arcsec). If `SEQ.JITTER.WIDTH` is set to zero, then the template will just nod between A and B. It is recommended to use a jitter box width smaller or equal to the nodding length to avoid any chance of overlapping of the spectra on sequential images.

If `SEQ.COMBINED.OFSET` is set to T and if guiding was started before the start of the template the telescope will guide with *Star-To-Box*. Guiding is recommended for observations longer than 15 min but close to the meridian or the zenith it may be required even for shorter sequences.

The templates have been optimized to minimize overheads. However, after a telescope offset, one or more DITs are skipped to make sure the telescope has stabilized after the move. Otherwise, when the telescope is not moved between frames (i.e. when `NINT`>1, or at the beginning of a new cycle) all `DIT`-s are kept.

At the end of the templates, the telescope returns to the original position if `SEQ.RETURN` is true (T). If not, the telescope is not moved at the end of the template.

SOFI_spec_obs_AutoNodOnSlit and SOFI_spec_obs_AutoNodNonDestr differ only in the control over the readout mode. The second template allows to define `NSAMP` and `NSAMPPIX` (as explained the section 3.4.1). Otherwise, they are identical. The only two additional parameters with respect to the SOFI_spec_obs_AutoNodOnSlit are `DET.NSAMP` and `DET.NSAMPIX`, respectively the number of samples and the sample number per reading. During the integration the signal is sampled a number of times defined by `DET.NSAMP`. The largest the number of samples the lowest the read out noise. However `DET.NSAMP` must not exceed 60, above this value in fact the glowing of the shift registers become the dominant source of noise. For long integrations `DET.NSAMP` between 20 and 40 is advisable. A way to further low the read out noise keeping `DET.NSAMP` small enough is to sample the video signal more than once. The number of sampling of the video signal is `DET.NSAMPIX`, 4 is a good number for this parameter. For long integrations DIT should not exceed 300 sec.

The following examples (Table C.31 and C.32) show typical parameters values. According to the `NINT` and number of cycles they produce 3x3x2 = 18 files, each of them corresponding to the average of the `DIT` x `NDIT`.

SOFI_spec_obs_GenericSpectro and SOFI_spec_obs_GenSpecNonDestr

These observation templates (Table C.33 and C.34) are for spectroscopy and they have the flexibility to do any sequence of telescope offsets whether they be combined offsets (offset the telescope and guide probe) or non-combined offsets (offset the telescope alone). SOFI_spec_obs_GenSpecNonDestr is identical to SOFI_spec_obs_GenericSpectro except for the non-destructive readout more.

With this flexibility of these templates comes complexity. They are meant to be used in situations that cannot be accommodated by the nodding templates described above, i.e when the target is too extended and to obtain sky spectrum one has to move further than the slit length allows.

Telescope offsets and guiding options are defined as lists in and `SEQ.OFFSETX.LIST`, `SEQ.OFFSETY.LIST` and `SEQ.GUIDING.LIST`. Telescope offsets are relative to the previous position, they are defined **along detector lines (X) and columns (Y)**, and they are in arcsec. **The slit is oriented along the N-S direction, i.e. along the X axis** (N to the left-negative and S to the right-positive) and E-W along the Y axis (E down-negative and W up-positive) for Rotation Offset on Sky

Parameter signature	Value
Exposure Name	NGC6118
DIT	40
NDIT	2
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Spectro Mode	LONG_SLIT_BLUE
Which slit	long_slit_1
Combined offset ? (F/T)	T
Jitter Box Width (arcsec)	20
Return to origin ? (T/F)	T
Nod Throw (arcsec)	100.
NINT	3
Number of AB or BA cycles	3

Table C.31: SOFI_spec_obs_AutoNodOnSlit. Example.

Parameter signature	Value
Exposure Name	NGC6118
DIT	50
NDIT	2
NSAMP	30
NSAMPPIX	4
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Spectro Mode	LONG_SLIT_BLUE
Which slit	long_slit_1
Combined offset ? (F/T)	T
Jitter Box Width (arcsec)	20
Return to origin ? (T/F)	T
Nod Throw (arcsec)	100.
NINT	3
Number of AB or BA cycles	3

Table C.32: SOFI_spec_obs_AutoNodNonDestr. Example.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures ?	SEQ.NEXPO	1	Number of exposures
Spectro Mode	INS.SMODE	NODEFAULT	Spectroscopic Mode
Which Slit ?	INS WHICHSLIT	NODEFAULT	Which Slit
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
X offset list (arcsec)	SEQ.OFFSETX.LIST	NODEFAULT	List of offsets in X (arcsec)
Y offset list (arcsec)	SEQ.OFFSETY.LIST	NODEFAULT	List of offsets in Y (arcsec)
Observation Type (S or O)	SEQ.OBSTYPE.LIST	NODEFAULT	Observation type: O - object S - sky
Guiding (N B S)	SEQ.GUIDING.LIST	NODEFAULT	Guiding: B - Box-To-Star, S - Star-To-Box, N - none

Table C.33: SOFI_spec_obs_GenericSpectro.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
DET.DIT	DET.DIT	NODEFAULT	Detector Integration Time; individual exposure (sec)
DET.NDIT	DET.NDIT	NODEFAULT	Number of DITs averaged into an individual image
NSAMP	DET.NSAMP	4	Number of Samples
NSAMPPIX	DET.NSAMPIX	4	Sample Number per Reading
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures ?	SEQ.NEXPO	1	Number of exposures
Spectro Mode	INS.SMODE	NODEFAULT	Spectroscopic Mode
Which Slit ?	INS WHICHSLIT	NODEFAULT	Which Slit
Return to Origin ? (T/F)	SEQ.RETURN	T	Returns the telescope to the original pointing if True
X offset list (arcsec)	SEQ.OFFSETX.LIST	NODEFAULT	List of offsets in X (arcsec)
Y offset list (arcsec)	SEQ.OFFSETY.LIST	NODEFAULT	List of offsets in Y (arcsec)
Observation Type (S or O)	SEQ.OBSTYPE.LIST	NODEFAULT	Observation type: O - object S - sky
Guiding (N B S)	SEQ.GUIDING.LIST	NODEFAULT	Guiding: B - Box-To-Star, S - Star-To-Box, N - none

Table C.34: SOFI_spec_obs_GenSpecNonDestr.

Parameter signature	Value
Exposure Name	NGC6118
DIT	40
NDIT	2
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of Exposure	6
Spectro Mode	LONG_SLIT_BLUE
Which slit	long_slit_1
Return to origin ? (T/F)	T
X offset list (arcsec)	0 −15 0 30 0 −15
Y offset list (arcsec)	0 0 10 −10 10 −10
Obs Type (O or S)	O O S O S O
Guiding (N B S)	S

Table C.35: SOFI_spec_obs_GenericSpectro. Example.

`TEL.ROT.OFFANGLEPA`=0 deg.

There are three guiding options N, B or S. For option N, the offsets are non-combined. Option B stands for Box To Star. In this case the telescope offsets by first moving with a non combined offset to the position where guiding was last enabled, and from there with a combined offset to the new position. Guiding is then started with Box To Star. Option S stands for Star To Box, and the offsets are handled as for B, except that guiding is resumed with *Star-To-Box*. With large combined offsets, the guide probe may not be able to follow the one guide star. In such a case, the guiding system will automatically find another star, and resume guiding. If any of the entries in SEQ.GUIDING.LIST are different from N, and if guiding is off at the beginning of the template, a pop up window prompts the user to start guiding.

The observation type can be defined for each image, and entered as a list in `SEQ.OBSTYPE.LIST`. O stands for Object and S stands for Sky.

In addition to observations that require large sky offsets, these templates are very useful for slit scanning across an object (i.e. simulation of 3D spectroscopy) by defining a list of offsets in the y direction (perpendicular to the slit direction). A third case when these templates can be used is when the user wants to obtain spectra at more than two positions across the slit - then the offsets will be only in the x direction.

These templates cannot by nature be easily optimized. After each exposure, one or more DITs are skipped.

At the end of the templates, the telescope is returned to the original position if `SEQ.RETURN` is set to true (T). If not, the telescope is not moved.

The lists can have any length; however having lists of different lengths can become extremely confusing. It is good practice to use either lists of one value, or lists of equal length.

The following examples (Table C.35 and C.36) demonstrate a typical usage of the generic templates. Six images will be obtained: 1- the object at the acquisition position; 2- the object in an offset position (−15 arcsec); 3- the sky, the object is off the slit; 4- the object at another offset position; 5- the sky again; and 6- the object at the original position. A figure with the object positions is also shown.

Each of the obtained 6 files is the average of 2 (`NDIT`) exposures of 40 sec (`DIT`). The guiding option asks to put the star to the box.

Parameter signature	Value
Exposure Name	NGC6118
DIT	40
NDIT	2
NSAMP	4
NSAMPPIX	10
Number of columns	1024
Number of rows	1024
First column of window	1
First row of window	1
Number of exposures	6
Spectro Mode	LONG_SLIT_BLUE
Which slit	long_slit_1
Return to origin ? (T/F)	T
X offset list (arcsec)	0 −15 0 30 0 −15
Y offset list (arcsec)	0 0 10 −10 10 −10
Obs Type (O or S)	O O S O S O
Guiding (N B S)	S

Table C.36: SOFI_spec_obs_GenSpecNonDestr. Example.

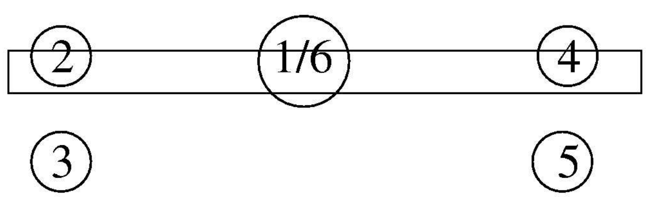

Figure C.1: Positions of the offsets in the slit.

C.3.7 SOFI Spectroscopic Calibration Templates

SOFI_img_cal_Darks

The template (Table C.20) for imaging darks can be used for obtaining spectroscopic darks, if necessary. However, notice that in practice this is never necessary because: (i) in case of observations the dark (including the "bias") is subtracted together with the sky, and (ii) in case of the calibrations the respective templates take frames with lamps off to be used as "darks".

SOFI_spec_cal_Arcs

This calibration template (Table C.37) takes arc spectra with the calibration unit. The calibration mirror is automatically inserted at the beginning of the template, and is automatically removed at the end.

The number of arc frames is defined by `SEQ.NEXPO`. Arc frames can be taken with different `DIT` and `NDIT` values, defined as lists with `SEQ.DIT.LIST` and `SEQ.NDIT.LIST`. `SEQ.SPECTROMODELIST` defines the spectroscopic mode, entered as a list with either B, R, Z, J, H, K or NB_1.061 standing for the available spectroscopic modes. In addition, different slits can be called sequentially, with `SEQ.SLIT.LIST`. The allowed values are 1, 2 or 0.6, for long_slit_1, long_slit_2 and long_slit_0.6, respectively. Finally, the arc lamps are entered into `SEQ.LAMP.LIST`. Valid values are N, Xe, Ne or B. N stands for None (this is why there is no need to take separate dark frames; but make sure to obtain at least one image with no lamp at each configuration!), Xe stands for Xenon, Ne stands for Neon, and B stands for Both, i.e. Xenon and Neon lamps simultaneously.

Nota Bene: Taking images with no lamp (the option N) has to be specified explicitely in the `SEQ.LAMP.LIST`! This is responsibility of the user. Remember, that these images are necessary to remove the bias/dark/scattered light contribution.

Note that there is no need to take the arc calibration with non-destructive readout because the DIT can always be increased to ensure that the arc spectrum has a sufficient signal-to-noise ratio. There is also no reason to match the readout mode of the arc calibration with the readout mode of the data.

SOFI_spec_cal_DomeFlats and SOFI_spec_cal_NonDestrDomeFlats

Spectroscopic dome flats are taken with these two calibration templates (Table C.38 and C.39). The only difference between the two templates is the readout mode - it has to match the readout mode used to obtain the scientific observations.

For each element in `SEQ.DIT.LIST` and `SEQ.NDIT.LIST`, the templates take four images: the first with the dome lamp off, the next two with the dome lamp on, and the fourth one with the dome lamp off. The intensity of the dome lamp is controlled manually.

Note that in case of SOFI_spec_cal_NonDestrDomeFlats it is not crucial that `NSAMP` and `NSAMPPIX` are the same for the science frames and calibrations. In fact, this is sometimes impossible because the `DIT` of the scientific exposure is rather long, often in order of 5-10 min. Good values for the parameters of the NonDestrDomeFlat templates are: `DIT`=10, `NSAMP`=6, `NSAMPPIX`=4.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures ?	SEQ.NEXPO	1	Number of exposures
List of DITs	SEQ.DIT.LIST	NODEFAULT	Detector Integration Time; individual exposure (sec)
List of NDIT	SEQ.NDIT.LIST	NODEFAULT	Number of DITs averaged into an individual image
Spectral Mode List	SEQ.SPECTROMODELIST	NODEFAULT	List of Spectroscopic Modes: B R Z J NB_1.061 H K
Slit List	SEQ.SLIT.LIST	NODEFAULT	Slit list: 0.6, 1, 2
Spectral Lamp List	SEQ.LAMP.LIST	N	Lamp list: N - none, B - both Xe - Xenon, Ne - Neon

Table C.37: SOFI_spec_cal_Arcs.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
Number of exposures ?	SEQ.NEXPO	1	Number of exposures
List of DITs	SEQ.DIT.LIST	NODEFAULT	Detector Integration Time; individual exposure (sec)
List of NDIT	SEQ.NDIT.LIST	NODEFAULT	Number of DITs averaged into an individual image
Spectral Mode List	SEQ.SPECTROMODELIST	NODEFAULT	List of Spectroscopic Modes: B R Z J NB_1.061 H K
Slit List	SEQ.SLIT.LIST	NODEFAULT	Slit list: 0.6, 1, 2

Table C.38: SOFI_spec_cal_DomeFlats.

Parameter signature	Header Keyword	Value	Description
Exposure Name	DET.EXP.NAME	SOFI	File name prefix
Number of columns	DET.WIN.NX	1024	Number of columns in the window
Number of rows	DET.WIN.NY	1024	Number of rows in the window
First column of window	DET.WIN.STARTX	1	First column of window
First row of window	DET.WIN.STARTY	1	First row of window
NSAMP	DET.NSAMP	4	Number of Samples
NSAMPPIX	DET.NSAMPIX	4	Sample Number per Reading
Number of exposures ?	SEQ.NEXPO	1	Number of exposures
List of DITs	SEQ.DIT.LIST	NODEFAULT	Detector Integration Time; individual exposure (sec)
List of NDIT	SEQ.NDIT.LIST	NODEFAULT	Number of DITs averaged into an individual image
Spectral Mode List	SEQ.SPECTROMODELIST	NODEFAULT	List of Spectroscopic Modes: B R Z J NB_1.061 H K
Slit List	SEQ.SLIT.LIST	NODEFAULT	Slit list: 0.6, 1, 2

Table C.39: SOFI_spec_cal_NonDestrDomeFlats.

Appendix D

Frame Types

There are several basis frame types, which are identified by three keywords in the FITS header. The full list is given in Table D.1.

Keyword	Value	Type
`DPR CATG`	SCIENCE	Exposure on target (object)
`DPR CATG`	OTHER	Exposure off target (sky)
`DPR CATG`	CALIB	Calibration frame
`DPR TECH`	IMAGE	Exposure in imaging mode
`DPR TECH`	SPECTRUM	Exposure in spectroscopic mode
`DPR TECH`	POLARIMETRY	Exposure in polarimetric mode
`DPR TYPE`	LAMP	Arc spectrum (comparison lamp)
`DPR TYPE`	DARK	Dark frame
`DPR TYPE`	STD	Standard Star
`DPR TYPE`	FLAT	Flat Field Frame

Table D.1: FITS header keywords defining the content of the images.

Appendix E

Photometric Standards

The majority of users prefer to calibrate their data with the NICMOS photometric standard stars (Persson et al. 1998 A.J. 116, 2475). Pre-prepared OBs for observations of most of the standard stars from this list are available at the telescope. For convenience, these standards that are observable from the Southern hemisphere are listed in Table E.1. Finding charts with 2x2 arcmin field of view are shwon in Figures E.1, E.2, E.3, E.4 and E.5. North is up and East is to the left.

No	HST	RA (J2000)	DEC	J	σ(J)	H	σ(H)	K	σ(K)	K_S	$\sigma(K_S)$
9101	P525-E	00:24:28.3	+07:49:02	11.622	0.005	11.298	0.005	11.223	0.008	11.223	0.005
9103	S294-D	00:33:15.2	−39:24:10	10.932	0.006	10.657	0.004	10.596	0.005	10.594	0.004
9104	S754-C	01:03:15.8	−04:20:44	11.045	0.005	10.750	0.005	10.693	0.010	10.695	0.005
9105	P530-D	02:33:32.1	+06:25:38	11.309	0.010	10.975	0.006	10.897	0.006	10.910	0.005
9106	S301-D	03:26:53.9	−39:50:38	12.153	0.007	11.842	0.005	11.772	0.010	11.788	0.006
9108	P533-D	03:41:02.4	+06:56:13	11.737	0.009	11.431	0.006	11.337	0.008	11.336	0.005
9109	S055-D	04:18:18.9	−69:27:35	11.552	0.002	11.326	0.002	11.255	0.027	11.269	0.002
9111	S361-D	04:49:54.6	−35:11:17	11.246	0.006	11.031	0.006	10.992	0.033	10.980	0.006
9113	S252-D	05:10:25.6	−44:52:46	11.059	0.005	10.776	0.005	10.708	0.034	10.713	0.005
9115	S363-D	05:36:44.8	−34:46:39	12.069	0.007	11.874	0.005	11.826	0.007	11.831	0.005
9116	S840-F	05:42:32.1	+00:09:04	11.426	0.009	11.148	0.009	11.077	0.014	11.058	0.008
9118	S842-E	06:22:43.7	−00:36:30	11.723	0.011	11.357	0.009	11.264	0.016	11.261	0.010
9119	S121-E	06:29:29.4	−59:39:31	12.114	0.006	11.838	0.005	11.765	0.009	11.781	0.005
9121	S255-S	06:42:36.5	−45:09:12	12.719	0.004	11.434	0.004	——	——	11.372	0.004
9125	S005-D	07:19:38.6	−84:35:06	10.885	0.007	10.598	0.006	10.514	0.013	10.522	0.008
9129	S209-D	08:01:15.4	−50:19:33	10.914	0.007	10.585	0.006	10.487	0.021	10.496	0.009
9132	S312-T	08:25:36.1	−39:05:59	11.949	0.006	11.669	0.005	11.608	0.004	11.609	0.004
9133	S495-E	08:27:12.5	−25:08:01	11.521	0.007	11.048	0.008	10.965	0.016	10.960	0.010
9134	P545-C	08:29:25.1	+05:56:08	11.881	0.007	11.624	0.005	11.575	0.005	11.596	0.006
9135	S705-D	08:36:12.5	−10:13:39	12.362	0.010	12.098	0.011	——	——	12.040	0.014
9136	S165-E	08:54:21.7	−54:48:08	12.489	0.008	12.214	0.008	12.138	0.018	12.142	0.011
9137	S372-S	09:15:50.5	−36:32:34	11.153	0.007	10.891	0.007	10.830	0.019	10.836	0.010
9138	S852-C	09:41:35.8	+00:33:12	11.354	0.006	11.041	0.006	10.981	0.015	10.982	0.008
9140	S262-E	09:45:42.8	−45:49:40	11.409	0.011	11.085	0.008	——	——	11.022	0.012
9141	S708-D	09:48:56.4	−10:30:32	11.081	0.008	10.775	0.008	10.715	0.035	10.718	0.010
9143	P550-C	10:33:51.8	+04:49:05	12.344	0.007	12.121	0.005	12.067	0.006	12.081	0.005
9144	S264-D	10:47:24.1	−44:34:05	11.642	0.009	11.335	0.008	11.263	0.018	11.280	0.010
9146	S217-D	12:01:45.2	−50:03:10	12.323	0.007	11.002	0.005	10.931	0.003	10.936	0.004
9147	S064-F	12:03:30.2	−69:04:56	12.111	0.007	11.803	0.007	11.722	0.013	11.724	0.007
9150	S791-C	13:17:29.6	−05:32:37	11.661	0.008	11.310	0.007	11.250	0.014	11.267	0.008
9153	P499-E	14:07:33.9	+12:23:51	11.947	0.008	11.605	0.008	11.560	0.013	11.540	0.008
9154	S008-D	14:23:45.5	−84:09:58	11.232	0.007	10.990	0.007	10.904	0.009	10.915	0.008
9155	S867-V	14:40:58.0	−00:27:47	12.045	0.008	11.701	0.005	11.622	0.005	11.633	0.005
9157	S273-E	14:56:51.9	−44:49:14	11.341	0.007	10.924	0.005	10.851	0.004	10.849	0.004
9160	S870-T	15:39:03.5	+00:14:54	10.914	0.008	10.701	0.008	10.649	0.010	10.659	0.009
9164	P565-C	16:26:42.7	+05:52:20	12.180	0.007	11.895	0.006	11.842	0.007	11.844	0.006
9170	S875-C	17:27:22.2	−00:19:25	11.132	0.005	10.835	0.005	10.739	0.006	10.744	0.005
9172	S279-F	17:48:22.6	−45:25:45	12.477	0.009	12.118	0.006	12.026	0.006	12.031	0.006
9173	S024-D	18:18:46.2	−80:06:58	11.039	0.007	10.778	0.007	10.693	0.009	10.711	0.008
9175	S071-D	18:28:08.9	−69:26:03	12.252	0.006	11.916	0.007	11.834	0.011	11.839	0.007
9178	S808-C	19:01:55.4	−04:29:12	10.966	0.007	10.658	0.008	10.566	0.014	10.575	0.008
9181	S234-E	20:31:20.4	−49:38:58	12.464	0.011	12.127	0.008	12.095	0.007	12.070	0.007
9182	S813-D	20:41:05.1	−05:03:43	11.479	0.005	11.142	0.005	11.082	0.010	11.085	0.005
9183	P576-F	20:52:47.3	+06:40:05	12.247	0.004	11.940	0.004	11.873	0.007	11.880	0.005
9185	S889-E	22:02:05.7	−01:06:02	12.021	0.005	11.662	0.004	11.586	0.012	11.585	0.005
9186	S893-D	23:18:10.0	+00:32:56	11.403	0.009	11.120	0.006	11.045	0.006	11.055	0.006
9187	S677-D	23:23:34.4	−15:21:07	11.857	0.003	11.596	0.003	11.538	0.009	11.542	0.003

Table E.1: NICMOS photometric standard stars (Persson et al. 1998 A.J. 116, 2475).

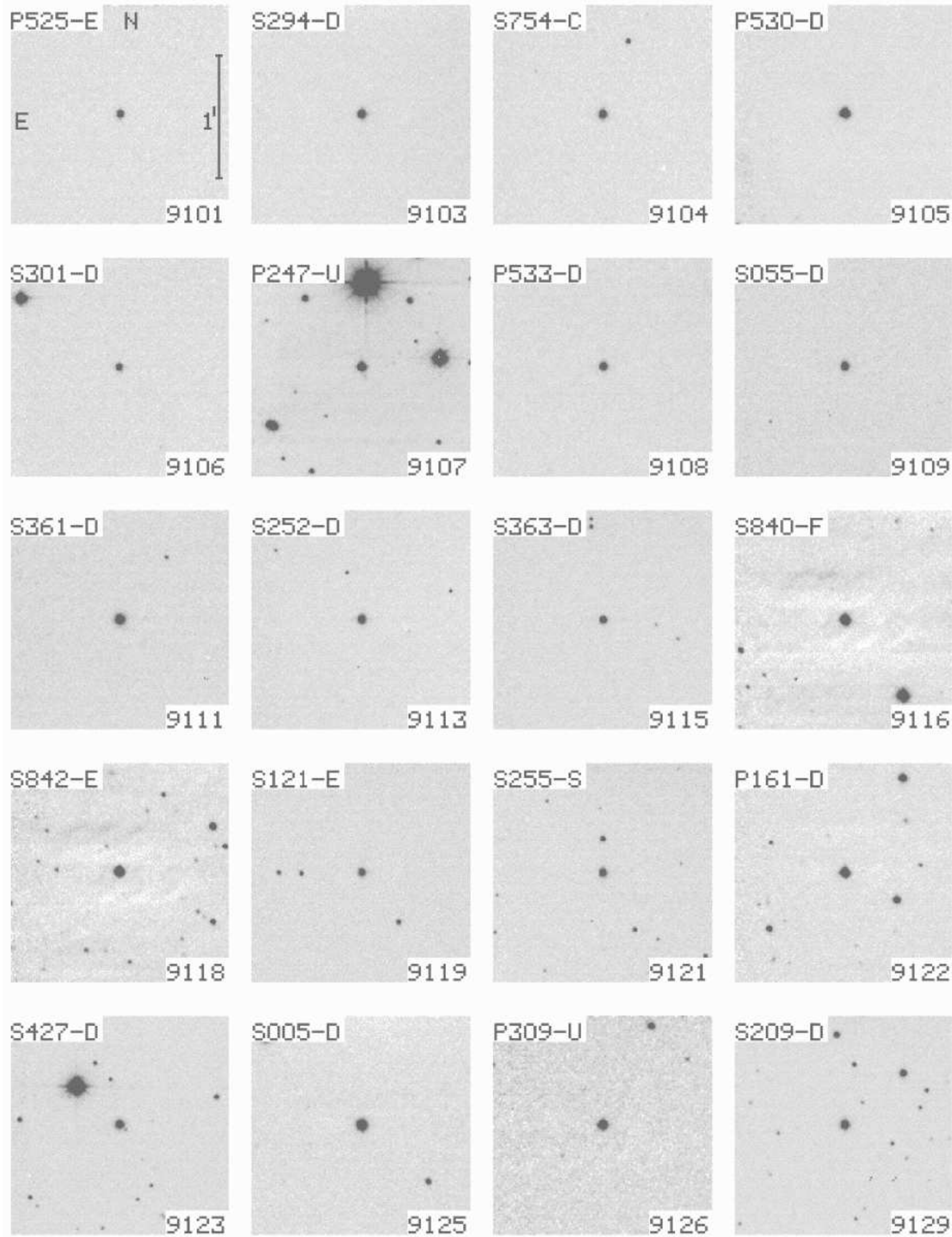

Figure E.1: Finding charts for the photometric standards of Persson et al. (1998). I.

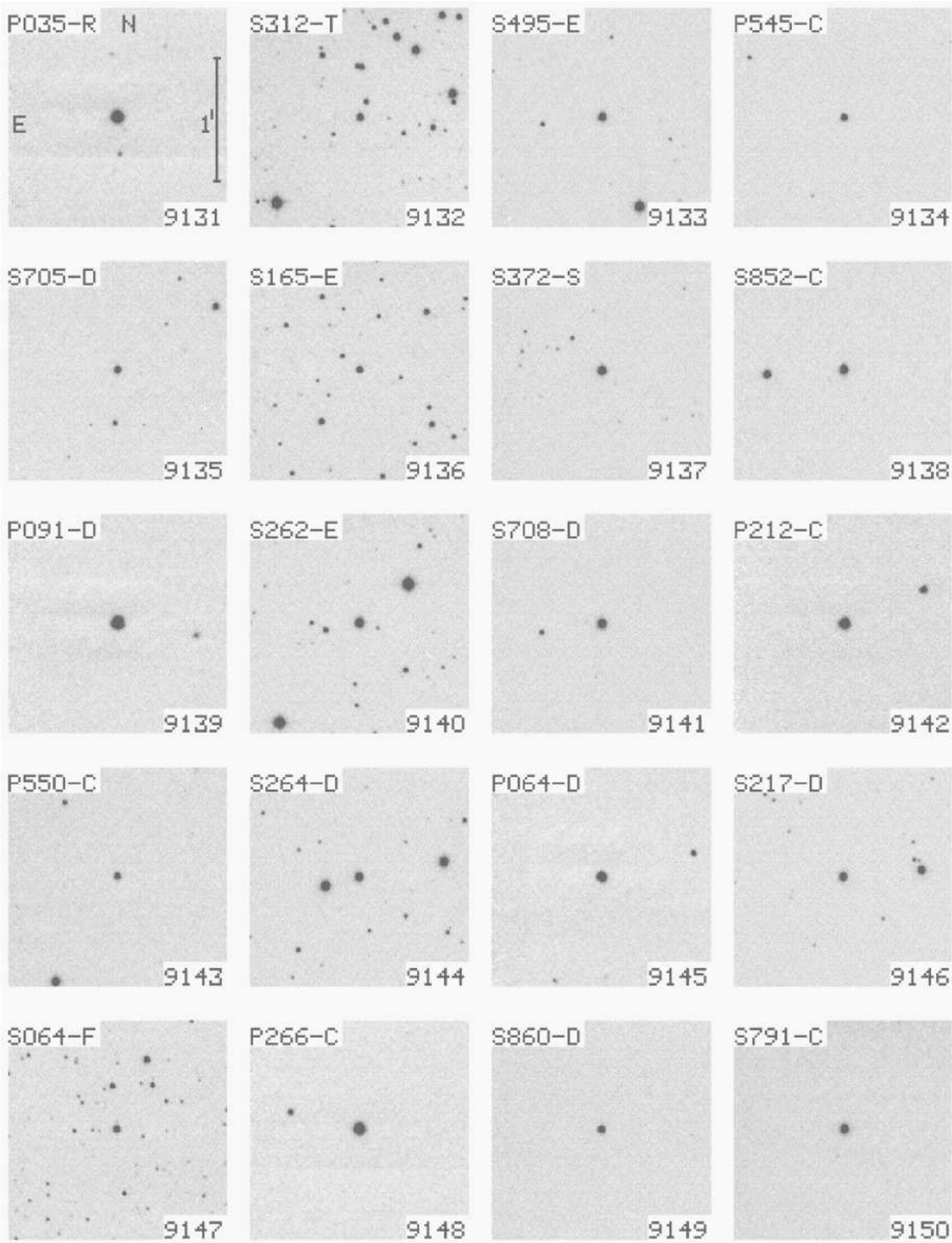

Figure E.2: Finding charts for the photometric standards of Persson et al. (1998). II.

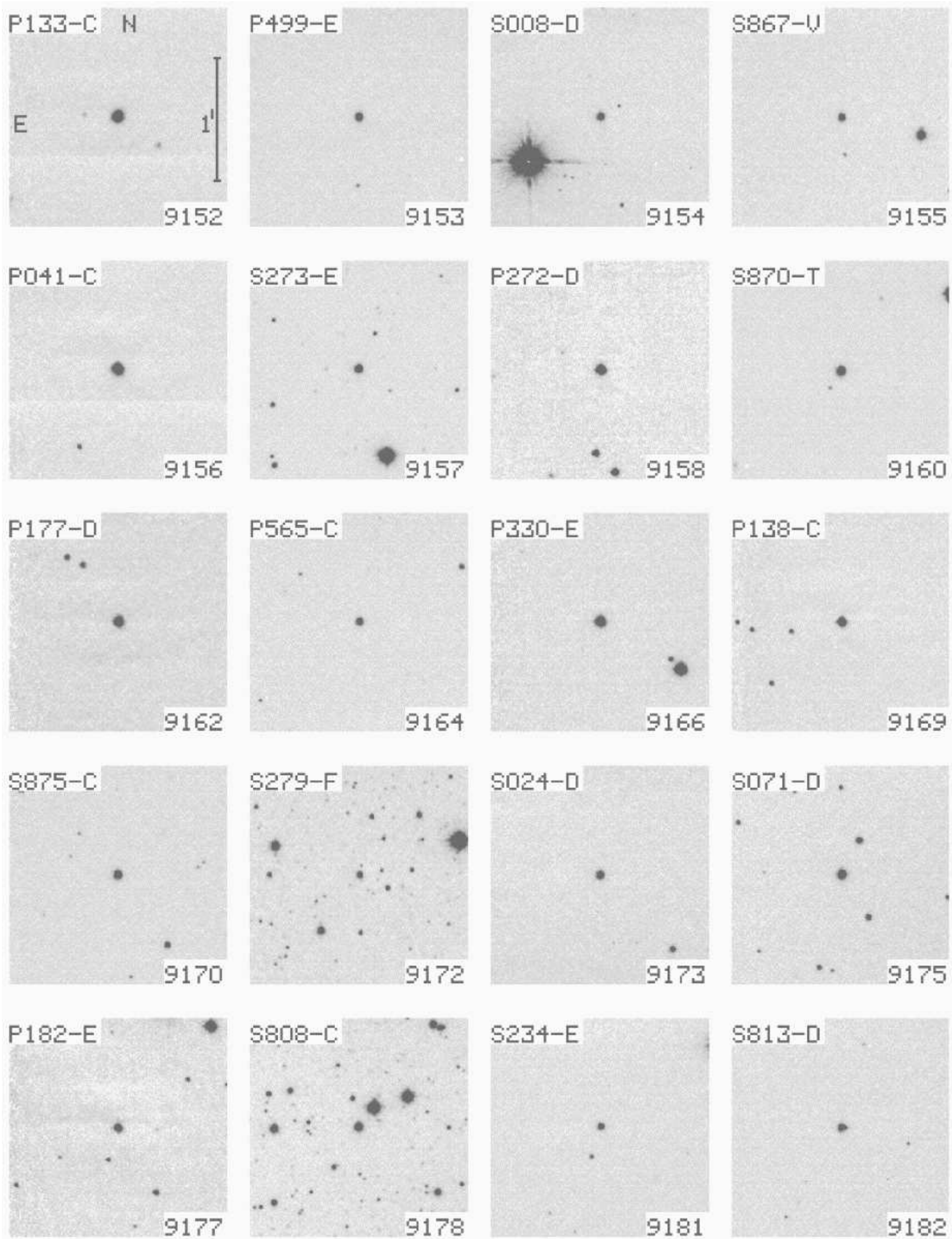

Figure E.3: Finding charts for the photometric standards of Persson et al. (1998). III.

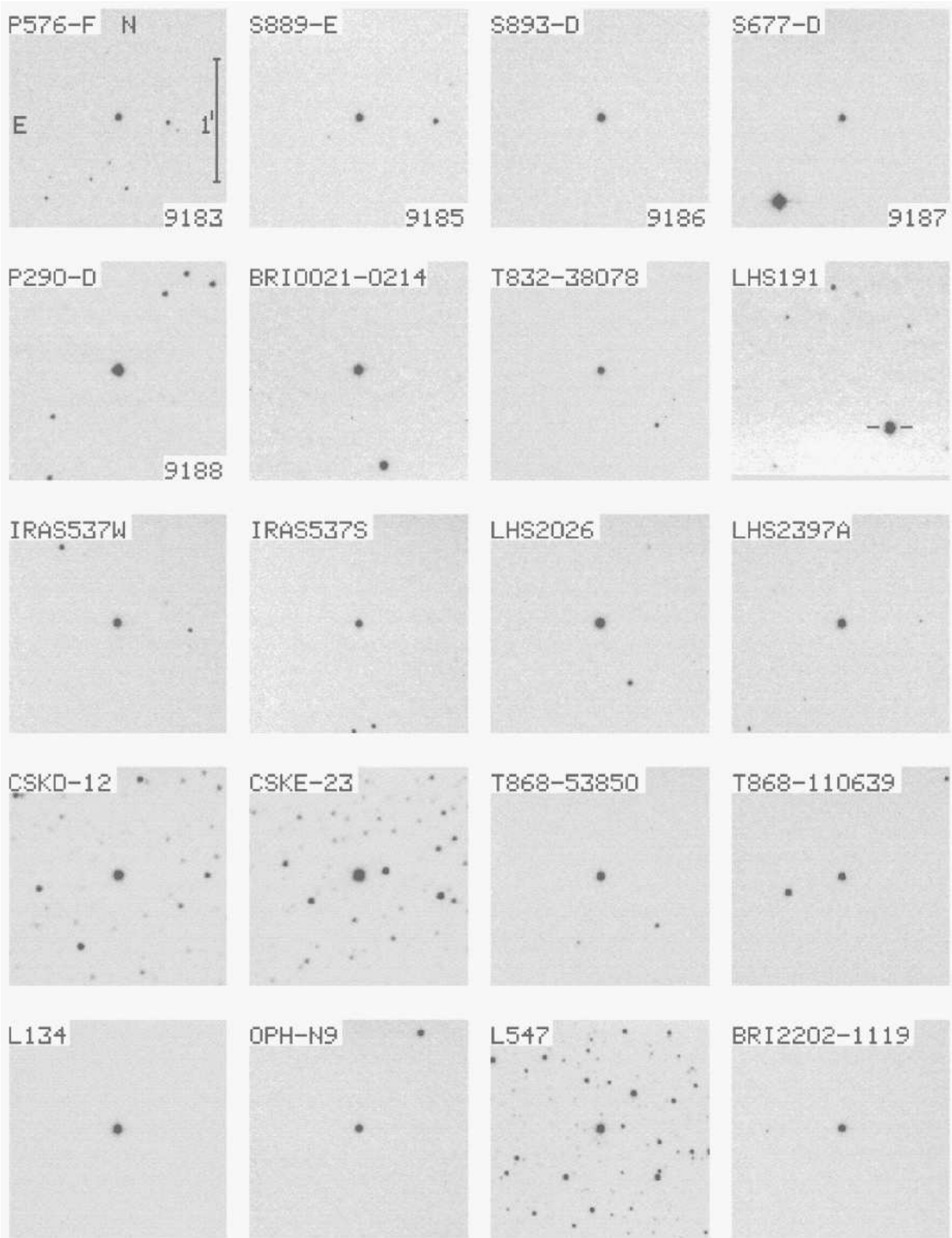

Figure E.4: Finding charts for the photometric standards of Persson et al. (1998). IV.

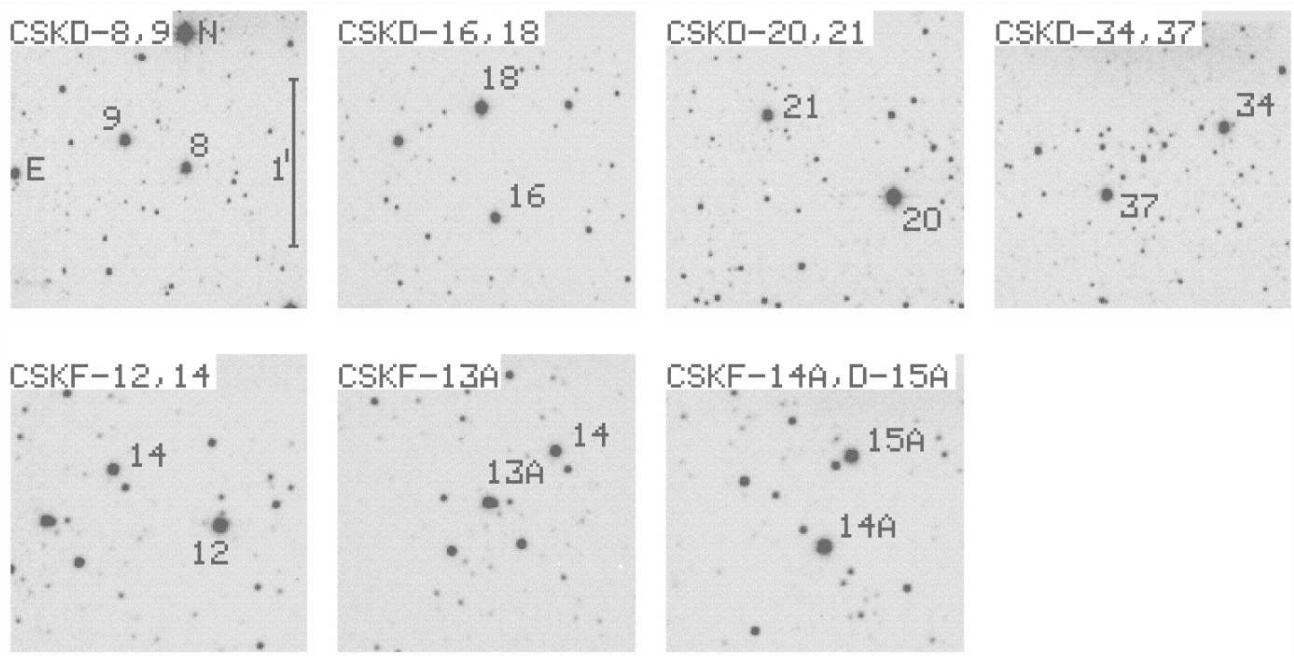

Figure E.5: Finding charts for the photometric standards of Persson et al. (1998). V.

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