European Southern Observatory

La Silla Observatory

La Silla SciOps

SUSI2
Superb Seeing Imager - 2
Direct CCD Imaging Camera at the NTT
User's manual

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0. Introduction

This manual describes the <u>SuSI2</u> instrument on the <u>ESO New Technology Telescope</u> at <u>La Silla Observatory</u>. It is meant for the observers preparing observations on that instrument, or processing data produced with SuSI2. The manual exists only in HTML. The on-line version has many in-line links to other pages. Nevertheless, a printed version from this document will contain all the relevant information: links that point to critical information are given in clear in the text, the others are for general or background information.

1. Instrument Overview

The NTT Nasmyth focus A hosts since 1998 two new instruments: the IR imager-spectrometer <u>SOFI</u> and the direct imaging CCD camera SUSI2. The latter is an upgrade version of the SUperb Seeing Imager identical in concept (imaging at the f/11 focus of the telescope with one additional reflection) but with a 4 times larger field (5.5 x 5.5 arcmin). SUSI2 incorporates the first version of new ESO controller FIERA with a mosaic of two 2k x 4k, 15 µm pixel, thinned, anti-reflection coated EEV CCDs. Other novel features of the instrument are an 8cm x 8cm sliding curtain shutter which permits uniform exposures down to 0.3 seconds and a special cryostat designed to operate on a rotating Nasmyth adaptor. SUSI2 and SOFI share the same mechanical structure attached to the Nasmyth adaptor flange and the same cable derotator. The direct beam from the telescope feeds SOFI. A 45° mirror is inserted in the light path when SUSI2 is in operation.

This manual is extensively based on the SusI-2 commissioning report and on the preliminary manual by S. d'Odorico and G.Martin.

2. Instrument properties

2.1 Optical parameters

Optical Components in the Light Path:
The optical path of SUSI2 includes the three mirrors of the telescope, the 45° reflection prism with a multi-layer coating (reflection efficiency > 90% in the range 340-500 nm; > 95% in the range 500-1100nm; this prims is known as "Mirror 4" in the NTT jargon) and the coated quartz window of the cryostat (transmission > 97% over the range 340-1100 nm).

The filter wheel and the shutter are located in the f/11 between the prism and the cryostat. Before Nov.1999, there was a small vignetted region at the bottom the the CCDs (~500pix). While the vignetting was flat-fielded out, this region should not be used for accurate photometry. The vignetting was caused by the mirror 4, whose position has been adjusted.

Filters:

The filter wheel has 6 positions. The filters have a diameter of 100 mm. The filters currently available are listed in the table below.

Table 1: SuSI2 filters.

Filter ID	Central wavel.	FWHM	PWL	Transm. %	Red leak and remarks
Bessel U #810	357.08	52.07	360.5	58.6	-
Bessel B #811	421.20	98.94	417.4	69.1	0.01% @ 1100nm 0.02% @ 1200nm
Bessel B #817	421.17	99.17	419.0	69.1	spare
Bessel V #812	544.17	115.17	526.0	89.4	0.01% @ 1100nm 0.02% @ 1200nm
Bessel R #813	641.58	158.89	597.0	86.9	0.06% @ 1100nm 0.04% @ 1200nm
Bessel I #814	794.96	147.82	797.5	88.9	0.13% @ 1100nm 1.63% @ 1200nm
Bessel Z #815	840.90	high pass	1126.0	98.2	Atmospheric + CCD cut off at large wavel.
r #822					not measured. Use at your own risk
IB 609 #830	609.38	27.16	610.0	88.9	***Not available anymore***
IB 662 #831	662.29	35.4	665.0	91.7	***Not available anymore***
WB 490 #824	502.72	107.32	510.0	87.5	-
WB 665 #825	665.67	123.52	679.0	97.4	-
U' #823	368.97	low pass.	339.0	81.0	Atmospheric + CCD cut off at small wavel. Maximizes transmission at l<370nm.
He II #880	469.531	7.644	469.0	72.2	-
H Beta #881	486.438	6.668	485.5	83.2	-
O III #882	500.984	7.244	500.0	86.1	-
O III/Cont #883	511.061	7.019	510.5	84.2	= O III 6000km/s
H alpha #884	655.528	6.976	656.5	89.5	-
H alpha/Cont #885	668.655	6.899	669.0	90.3	= H alpha 6000km/s

Notes on the filters:

- It was though for a while that Filter B#811 was causing an elongation of the image in case of very good seeing. This could not be confirmed; indeed B#811 gives images of excellent quality.
- Filters IB 609 and IB 662 are **not** available anymore.
- Additional information (incl. transmission plots) are available in Annex A, or on the La Silla Instrumentation web page ar http://filters.ls.eso.org/efs/, or from the team.
- Remark the *very* high peak transmission of these filters (up to twice that of similar filters in EMMI).
- Because of their extremely high costs, we do not plan to purchase any additional filters. If you need currently unavailable filters, you can send us (ls-imaging@eso.org) a request with

a scientific justification. However, be aware that it is unlikely that we have funds to acquire the filters.
- ○ Special filters can be mounted in SuSI upon request (with advance notice). The filters must respect the following specifications:
  - Diameter < =100mm
  - Thickness < 10mm

Filters with a dimeter < 100mm must be mounted in an adaptor. We have a set of such adaptors for some standard diameters, and we can manufacture adaptors for other diameters. It is critical to organize this in advance. Be warned that it is very likely that special filters will have a different optical thickness than the standard filters, causing a focus offset that will have to be measured and cause some additional overhead during the observations.

2.2 CCDs

The two EEV CCD 44-80 were the first in the large format with 2 x 4 k, 15µ pixels in operation for astronomy. Their properties when operated with the FIERA controller are summarized below:

Data Format, Read-out Time and Read-out Noise:
The two EEV chips are identified as ESO CCD # 45 and 46. The two frames are combined in a single FITS file (chip #45 has lower x values, i.e. on the left on standard display); the space between the two chips has been "filled" with some overscan columns so that the respective geometry of the two chips is approximatively preserved. The format of the file is 4288 x 4096. Along the x axis there are 50 prescan, 2048 active, 46 overscan pixels for chip # 45, followed by 50 prescan, 2048 active and 46 overscan for chip # 46.

There is one single read-out option in which the two chips are read in parallel each through a single port at 2×10^5 pixels/sec. There are three binning options (unbinned=1x1, 2 x 2 and 3 x 3) and the possibility of defining a single read-out window (which can overlap with both chips).

The read-out times (intervals from the closure of the shutter to the display of the image in the Real Time Display monitor) are 56, 16 and 9 seconds for the three binning options respectively.

On the RTD, the default options show North at the top and West (chip # 45) to the left.

The measured read-out noise are: 4.7 e- for (# 45) and 4.6 e- for (# 46). For the latest measurements of the CCD parameters, pls check the NTT detector page at http://www.ls.eso.org/lasilla/sciops/ntt/CCDs/CCDs.html on the WWW (updated ~weekly). This page also links to an history of these parameters' evolution.

CCD QE:
Measurements of the Qes for the two chips in the ESO detector laboratory show that # 45 is up to 5% relatively more efficient than # 46. The table below gives the average values:

Table 2: SuSI2's CCDs quantum efficiency

nm	350	400	500	600	700	800	900	1000
% QE	76	90	84	80	68	48	23	4

Saturation and Linearity:
Pixel saturation occurs at ~ 150000 e-. With the adopted gain of ~2.25 e- /ADU this corresponds

approximately to the full rang e of the ADC converter in the unbinned mode . The CCDs have been found linear within $\pm$ 0.15% over the full range 0-60000 ADUs.

Charge Transfer Efficiency:
Both serial and horizontal CTE are better than 0.999999.

CCD dark current:
<0.5 e-/pix/hour, i.e. negligible for all practical purposes.

Bias Level:
To be derived from the average of prescan and overscan regions of each frame because of a slight dependence on the mean level of the charge in each row of the CCD. 0sec bias exposure average at ~300adu.
(*again, check the* <u>*NTT detector web page*</u> *for up to date values*)
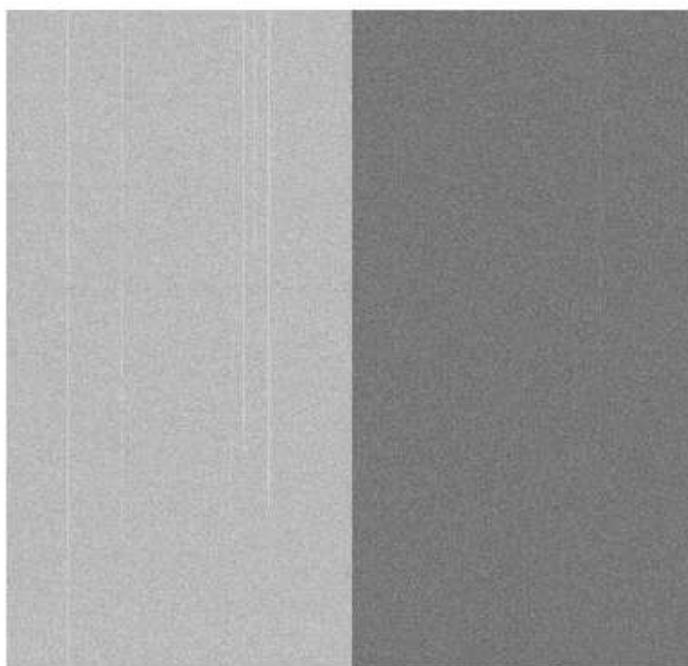
Figure 1: Example of SUSI bias: the difference of sensibility bewteen the two CCDs is responsible for the contrast.

Cosmetics:
Chip #45 (left) present ~15 bad columns, while #46 has some blemishes that look quite bad but actually flat-field out very well.

Image scale, Field Size, Image Quality:
The scale at the Nasmyth focus of the NTT is 5.4 arcsec/mm. The measured pixel scale is 0.085 arcsec/pixel (0.161 arc/sec in the 2 x 2 binned mode). Each chip of the 2x1 mosaic covers a field of 5.5 x 2.7 arcmin. The gap between the chips corresponds to ~ 100 real CCD pixels, or ~ 8 arcsec. In the default position of the rotator the gap runs in the N-S direction. The optical axis -which is also the reference for pointing- is at about 60 pix left of the center of the mosaic, i.e. in chip #45 (left), very close to the inter-CCD gap.

The angular misalignment between the two chips is smaller than 6 arcmin. Very accurate astrometry requires an independent calibration of the two subfields. The table below lists the mean astrometric parameters over the two chips.

Variable	X coefficient	Y coefficient

X	+0.02239	−0.00033
Y	+0.00013	+0.02231
XY	+0.00005	+0.00004
X2	−0.00004	+0.00003
Y2	−0.00004	−0.00001

No aberrations or change of focus have been detected over the full field covered by the mosaic down to an image quality of 0.5 arcsec FWHM.

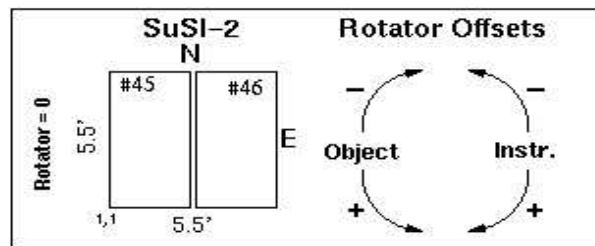The chip geometry is summarized in Fig.1, with the effect of an additional Rotator Offset.

Figure 2: Orientation of the SuSI2 detectors

2.3 Photometry and Throughputs

The photometric parameters have been determined during the commissioning of the instrument, and are measured regularly as part of the Maintenance Plan of the NTT. Typical values (for 2001) obtained using several Landolt standard fields are presented hereafter for the Bessel filters. It should be noted that the zero points show a slow decrease over the past two years, which is being investigated. Obviously, these values should be used only as reference: careful observers will re-measure them during their run. This is specially true for the Zero Points, whose values are strongly affected by the normalisation region used when preparing the flatfields.
Up to date values can be found at :

http://www.ls.eso.org/lasilla/sciops/ntt/susi/docs/susiCounts.html

Table 3: SuSI2 Photometric
Calibration
(typical 2001 values,
zero points in ADUs)

U − u =   0.10(U−B) + 23.52
B − b = −0.22(B−V) + 25.46
V − v = −0.02(V−R) + 25.70
R − r = −0.05(R−I) + 25.60
I − i = −0.10(R−I) + 24.60

For the purpose of observation preparation, an exposure time calculator for SUSI2 is available at this web site. It computes the counts of the instrument based on the optics and CCD data as they are known now. The results are in good agreement with the number of photo-electrons measured at the telescope. The table below gives the average measurements normalised to a star of 15

magnitude, in one second exposure and at 1 airmass, for two epochs. The stability of countrates is excellent, as illustrated by the evolution curves displayed at the above web page.

Table 4: Count rates (in adu) on SUSI2, for a mag=15 star, arimass=1

Band	U	B	V	R	I
CCD#45	4780	31200	46050	45100	18200
CCD#46	4690	30840	45770	44920	17950

3. Observing with SuSI2

3.1 Generalities

SuSI2 is entirely operated within the VLT observation scheme: "Observation Blocks" are prepared the days before the observations using P2PP, and executed at the telescope. It is also possible to create, copy and modify the Observations Blocks at the telescope; actually, the most efficient way to observe (in visitor mode) is to prepare in advance all your Target Packages and Observation Descriptions, while preparing only models of Observing Blocks, which you will duplicate and modify while observing. If the last sentence does not make any sense to you, don't dispair: your support scientist will introduce you to P2PP. You may also want to read the P2PP User's Manual, a complete, detailed, reference document.

The instrument templates (describing the different possible observations, calibration and target acquisition) are operationally identical to those which have been used with the previous SUSI imager, and are described in details in the SuSI2/EMMI Template Signature File Parameters Reference Guide. A short summary is given in the table below. Curious readers can consult the EMMI user manual for a longer description of the VLT observation scheme at the NTT.

Note that as of Period 68 (Oct.2001), a new set of SuSI2 observations templates has been introduced (known as SuSI2001). As of Period 69 (April 2002), the old templates are not supported anymore and new OBs must be prepared using SuSI2001.

Table 5: SuSI2001 Templates

Template	Correspondance with old template	Description
Acquisition Templates		
SUSI_img_acq_Preset	SAT01	Open loop (blind) pointing
SUSI_img_acq_MoveToPixel	SAT02	Target field at location (brings the object to a given pixel after taking a short acquisition image)
Observation Templates		
SUSI_img_obs_Exposure	SOT01	Single image
SUSI_img_obs_Jitter	SOT02	Multiple images with dithering (offsets)
SUSI_img_obs_DoubleW	-	Reads two non overlapping subwindows (for fast photometry)
Calibration Templates		
SUSI_img_cal_Dark	SCT01	Biases and Darks
SUSI_img_cal_DomeFF	SCT02	Dome flat-fields (request a series of flat at a given level)
SUSI_img_cal_SkyFF	SCT03	Twilight flat-fields (request a series of flat at a given leve, computed taking into account a model of the sky brightness de/increase)
SUSI_img_cal_TelFocus	SCT04	Through-focus sequence

3.2 Hints

This section lists a collection of hints and tips for observing with SuSI2. At this point it is not ordered in a very coherent way.

- **Central gap:**
    - Remember that there is a 8" gap between both chips, that the optical axis (i.e. the reference for pointing) if in CCD#46 (left) very close to the gap, and that NTT points very well. If you just preset to the coordinates of a star, your object can fall into the gap. You can either add/subtract 1-2 arcsec to the RA of the star (beware of the cos(dec)) or start your sequence with an offset (e.g. in a SUSI_img_obs_Jittertemplate).
    - As the space between the CCD is masked, the central gap can be used as a crude coronograph to mask a bright star. To accurately point an object in the gap, use the SUSI_img_acq_MoveToPixel acquisition template.

- **Standard stars:** Although both chips are very similar, you may want to photometrically calibrate them separately if a very accurate calibration is required. An efficient way to do so is to observe each standard field through all your filters, then rotate the rotator by 180deg and do the same sequence again. In that way, all the stars that were on one chip during the first sequence will fall on the other chip for the second sequence, ensuring that both are calibrated exactly in the same way. The rotation takes ~20sec. In practice, you can define an

OD with your standard exposures, and link it in two different OBs, one with a 0° rotator offset in the aquisition template (SUSI_img_acq_Preset), the second with a 180° offset. The jp2pp-impex-stdcal directory of the NTT machines (both off- and on-line) contain a set of pre-defined OBs for selected Landold fields, for standard read-out modes, and for 0 and 180deg rotation.

○ **Jitter and super-flatfield:** To obtain a very good flat-field, it is **critical**to use the "super-flat" technique (introduced by Tyson, developed by Tyson, Lilly, and others), which consists in utilizing the scientific images themselves as flatfield. In order to do so, the telescope should be moved (jittered) between each exposure. The size of that jitter should be of the order of 2x the largest object in the field. The jitter pattern should be chosen depending on the total number of exposures on each field, remembering that there is a vertical gap between the chips (i.e. never do an offset along the y axis). For a small number of exposures, a tilted grid gives good results. For larger number of exposures, consider taking the exposures moving the telescope on a "star-like" pattern, all the positions falling on a circle (typical radius = 15"), or, even better, taking the offsets at random within a disk of ~15" radius. If your object is very large, consider moving the object from chip to chip after each exposure, as one would "nod" the telescope for Infra-Red observations.

○ **Fringes in I:** Images obtained in the I filter present some strong fringes, caused by the interferences of night sky lines in the thin CCDs. As the flat fields are obtained with white light, they do not correct these fringes. Moreover, the fringes correspond to an additive pattern, and should therefore be subtracted, and not divided. To correct them, the fringe pattern has to be extrated from the scientific images themselves. The following procedure gives very good results; it should be however noted that, as the flatfielding of the frames, the corrections of the fringes can be performed in several different ways. This procedure is the simplest that gives good results.
  ■ Obtain the observations with a large dithering pattern; be sure to have at least 5 long exposures in I, ideally at least 5 per field.
  ■ Subtract the bias from all frames
  ■ Normalize the sky level of all your I exposures to the average sky level (you may want to work field by field). Store the normalization factor for further use.
  ■ Median average all the I exposures (again, you may want to work field by field); the result should contain no object, just the fringes and the flat-field structure.
  ■ Divide the result by the twilight I flat; you are left with a flat sky and the fringes (which have also been divided by the flatfield which they should not. This will be corrected later).
  ■ Get the average sky level and subtract it(you want to have an image with a mean~ zero) ; you are left with the flatfielded fringes alone.
  ■ Multiply the result by the flatfield: this is your master fringes template.
  ■ For each image, multiply the master fringe template by the normalization factor you used for that image.
  ■ Subtract the result from the original image
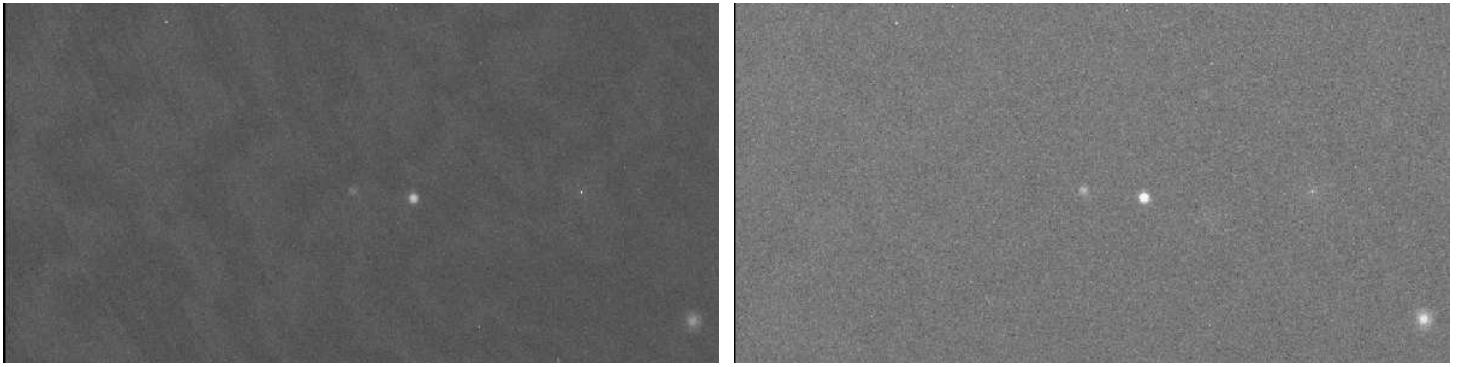 ■ Divide the defringed frames by the twighlight I flat.
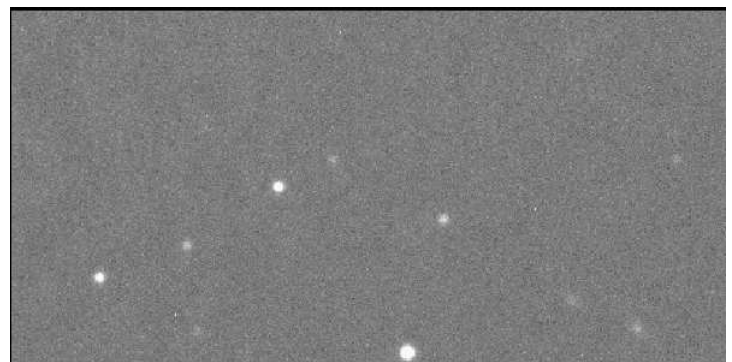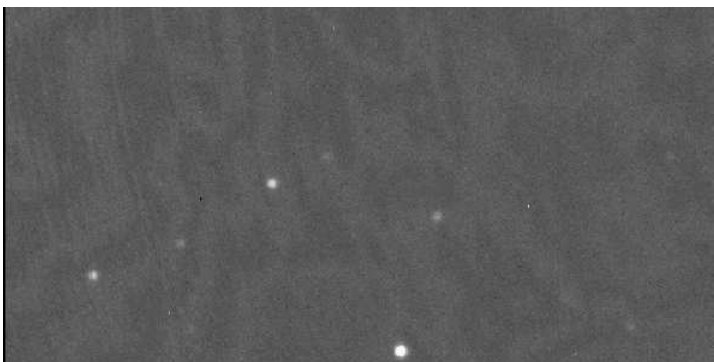
Figure 3: Left Panel : Dirty image in I. Right panel : Clean image in I.
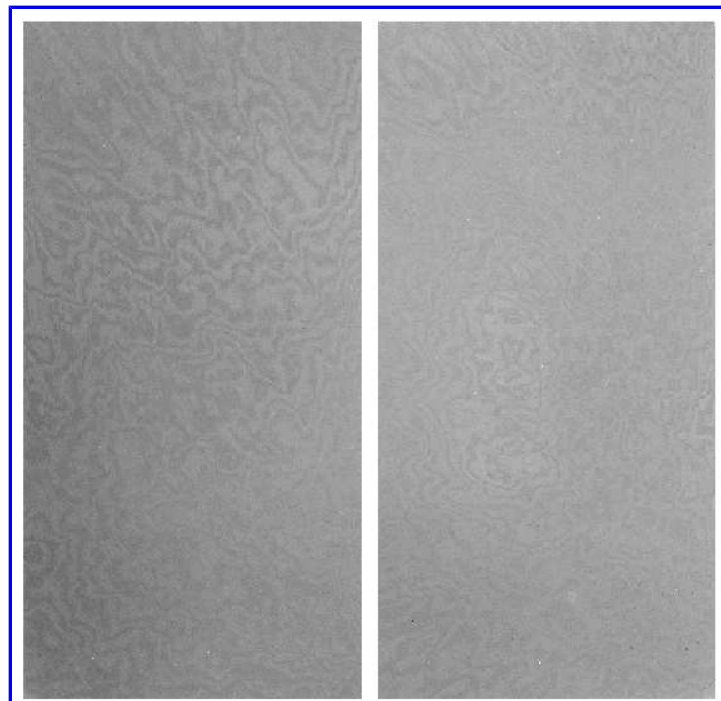

Figure 4: The fringing pattern

You can retrieve the fits file corresponding to a "classical" fringing pattern: click on the Figure 4. We built it with 34 images in I. The exposure time of all the images is 600s. If you don't want to build your own fringing pattern (and we recommend that you build your own pattern!) you can use this one : but take care to 1- flat field it with your sky flat (the pattern_raw.fits is not flatfielded), 2- adjust for the exposure time, and 3- adjust for the difference of the intensity level. For the latter, you can take as first approximation the ratio of the mean level of the science image by the mean level of the fringing pattern and multiply the fringing pattern by this factor. Then, subtract this corrected fringing pattern to your images. It looks not too bad (see the Figure 3 for an example), but if you want to do precise photometry, you have to do fine tuning and adjust the factor for each image.

○ **"Fast Photometry":** It is possible to define sequences of many windowed frames in order to sample the lightcurve of a rapidly varying object.

Figure 5: Example of window

For example, the window presented above has a size of 100 x 400 pixels. The mean dead time between two images is 13 s, with an exposure time of 10.00 s in the 3x3 mode, so a sampling time of 23s.To use this mode, use the following procedure:

- acquisition template: SUSI_img_acq_Preset (blind acquisition)
- a test exposure with full frame and bin 1x1, SUSI_img_obs_Jitter, with an offset to move the object of interest out of the gap.
- Once this image is displayed, measure the position of the object of interest (x,y in pix on the RTD), and define the read out window in a SUSI_img_obs_Jitter template:
  - window TRUE
  - start: x-50, y-50
  - size: 100, 400
  - number of exposures: 1
- excute that template, and check that the object is well centered. Adjust the start values of the window and retest if needed.
- modify the number of exposures to the number requested (eg 500), and start.

Additionally, another template (SUSI_img_obs_DoubleW) has been introduced to perform fast photometry of two objects (e.g. a variable star and a reference star) using two non-overlapping windows. Proceed as above to define the two sub-windows.To decrease the read-out-time between two exposures, you can use the 2x2 mode or even better the 3x3: if you look for short variations in photometry, you are not really interested by the resolution, but by the minimisation of the dead time. Example of light curve obtain with this method:
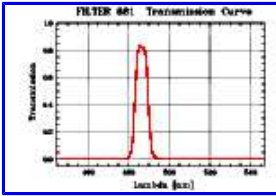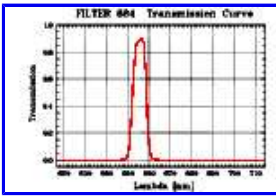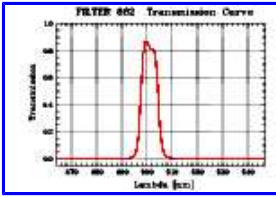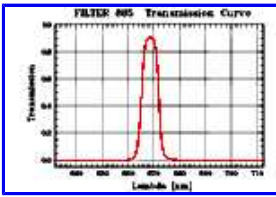

Seconds
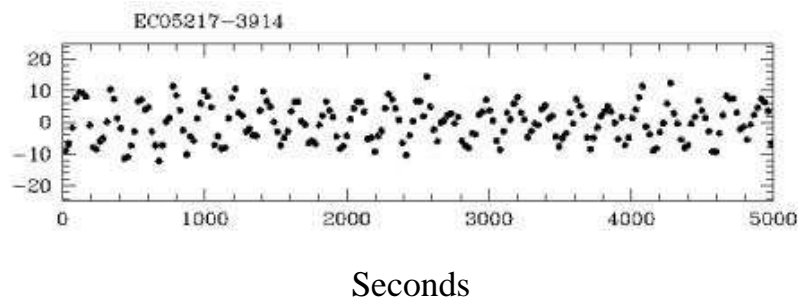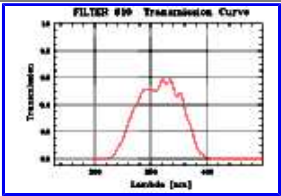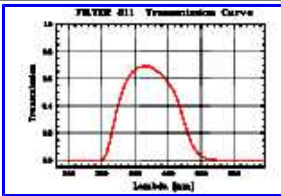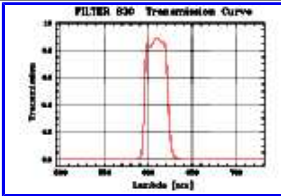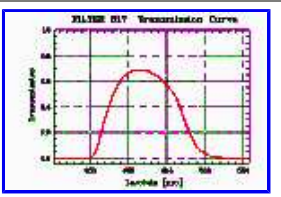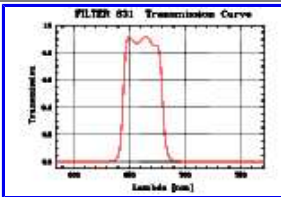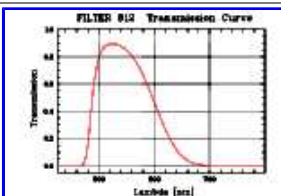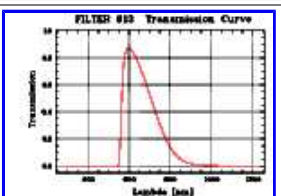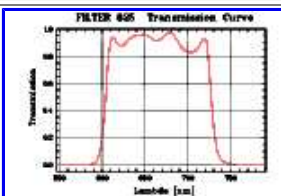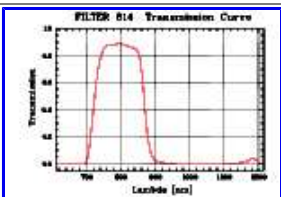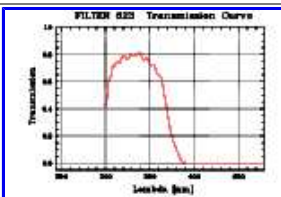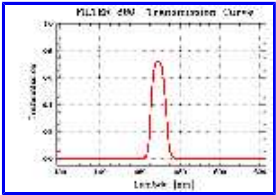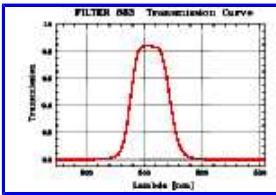
Figure 5: Example of photometric light curve of variable star with SUSI2 in mmag.

- **Vignetting and M4 coating:** until Nov.1999, the lowest part of the CCDs (~500pix) was slightly vignetted by M4 (this region should not be used for accurate photometry). It was also discovered in Jul.1999 that the coating of M4 was damaged, resulting in a slightly higher diffusion. Both problems were solved in Nov.1999 by the replacement of M4, which is now well aligned.

- For further assistance, feel free to contact us at ls-imaging@eso.org

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Annexes: Filter Transmission Curves

Filter (click for ASCII file)	Plot (click on thumbnail)	Filter (click for ASCII file)	Plot (click on thumbnail)
Broad band		**Special**	
Bessel U #810		r #822	
Bessel B #811		IB 609 #830	
Bessel B #817		IB 662 #831	
Bessel V #812		WB 490 #824	
Bessel R #813		WB 665 #825	
Bessel I #814		U' #823	
Bessel Z #815			
Narrow Band			

He II #880		O III/6000km #883	
H beta #881		H alpha #884	
O III #882		H alpha/6000km #885	

Release History

Release	Date	Changes and Comments
0.1	20 Mars 1998	First version, by Sandro D'Odorico and Gabriel Martin
0.2	20 Nov. 1998	Added filters, photometry, etc. O.Hainaut
0.2.1	1 Dec. 1998	Hints and transmission curves. O.Hainaut
0.2.2	18 Dec. 98	Added note on vignetting
1.0	19 Apr. 99	several additions (B#817, orientation, corono...)
1.1	19 Jun. 99	Added 2d throughput epoch
1.2	20 Aug 1999	Added narrow band filters
1.3	30 Nov 1999	fast photometry, and few typos fixed
1.4	31 Aug 2000	New version of the zero point and count rates
1.5	7 Feb 2001	updates (oh)
1.6	25 Aug 2001	updates (oh)
1.7	30 Dec 2001	updates (oh)
1.8	26 Aug 2002	update (mb)
1.9	13 Aug 2004	Most links broken. Repaired (FSE)
1.9.1	29 Aug 2004	Changed Doc. No. from LSO-MAN-ESO-40100-0002 to LSO-MAN-ESO-90100-0012 and archived (FSE)
1.10	30 Aug 2004	Made the header ISO9000 conformant (FSE)

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