1 Ultra-VISTA: an Ultra Deep Survey with VISTA

PIs: James Dunlop[1], Olivier Le Fèvre[2], Marijn Franx[3], Johan Fynbo[4],
[1] ROE, UK, [2] Laboratoire d'Astrophysique de Marseille, France, [3] Leiden Observatory, Netherlands, [4] Dark Cosmology Center, Denmark

1.1 Abstract

The survey speed of VISTA will be unparalleled until the JWST mission. The ULTRA-VISTA survey will exploit this capability by performing a combined ultra deep, narrow band, and wide, multiband YJHK$_s$ imaging survey on the COSMOS field, with 1409, 180, and 212 hours of observing time, respectively. The ultra-deep survey in 0.73 deg^2 will open the study of the universe between $z = 6.5$ and $z = 10$, producing a sample of > 1000 galaxies with $z > 6.5$, thereby enabling to study the sources causing reionization with a proper sampling of the luminosity function, and map their evolution well before JWST. The narrow band imaging survey in the deepest 0.73 square degrees is expected to find $\simeq 30$ Ly-α emitters at $z = 8.8$. At redshifts $z = 2$ to $z = 5$, adding the wide survey over the full 1.5 deg^2 area to the ultra-deep survey will provide unique mass selected samples down to $M_{stars} \simeq 10^{10}$ M$_\odot$, to follow the build up of mass across the peak in star formation activity. This survey will have unprecedented legacy value, and will be used for follow-up studies with VLT, ALMA, ELTs, and JWST.

2 Survey Observing Strategy

The ULTRAVISTA survey is unlike the other surveys, as it targets only 1 field (the COSMOS field). It will consist of multiband YJHK$_s$ and narrow band imaging of that field. The full 1.5x1 degree field will be imaged first, and later an ultra-deep image will be taken of 4 columns in the field (see Fig. 1)

The aim is to achieve similar image quality in all bands, and to build up depth simultaneously in all bands. The survey will continue over a period of 5 years, taking most of the time on the VISTA telescope when the field is visible.

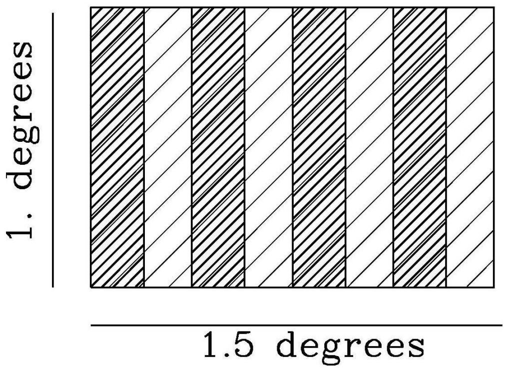

Fig. 1. The layout of the ULTRA VISTA field around the field center RA,DEC=10:00,+2. The shaded area is the full area of the wide survey, the dark area delineates the area of the deep survey.

2.1 Scheduling requirements

The total amount of observing time is 1800 hours, distributed over 5 years. The ratio of time over even and odd periods (detailed in the table below) is chosen under the assumption that we are allocated a fixed fraction of all the time when the field is visible (above airmass 2). The survey is expected to run for 5 years, from start 2008 to start 2012 (Deo Volente)

We request clear weather, including photometric weather.

We request the best 75% of seeing conditions, and according to the seeing statistics for Paranal, effects, this should give a seeing better than 0.8 arcsec as measured on the detector. This seeing estimate includes telescope/detector image degradation. Obviously, this still needs evaluation when the telescope is working. We will need to adapt the seeing limit if the telescope performance is worse than expected (or if the atmospheric seeing worsens), so that we can reach the required hours of exposure time.

Period	Time (h)	Mean RA	Moon	Seeing	Transparency
P80	292	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P81	68	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P82	292	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P83	68	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P84	292	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P85	68	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P86	292	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P87	68	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P89	292	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear
P90	68	10h	Y+NB: dark; Y,J not near astr. twilight	<0.8	clear

The distribution of integration time over the fields and filters is given in the Table below.

The survey will work under all moon conditions, but it is expected that a constraint will need to be given on the moon distance. This will need to be evaluated carefully, preferably during commissioning. We notice that our survey is likely to have moon distance constraints different from other surveys which go less deep. It might be that some filters work better at small moon distances than others. We will do the Y and narrow band filter preferentially in dark time.

There are no time constraints, apart from the constraints listed above.

	Ultra Deep Survey				**NarrowB**	**Deep Survey**			
	Y	J	H	K_s	NB1185	Y	J	H	K_s
Time & depth									
Total Integration Time over field (h)	315	315	315	315	168	47	47	47	47
Depth (5 σ) AB	26.7	26.6	26.1	25.6	24.1	25.7	25.5	25.1	24.5
Observing strategy per 1-hour OB									
Detector Integration Time (DIT) (sec)	60	30	10	10	120	60	30	10	10
Exposure co-adds (Ndit)	2	4	12	12	1	2	4	12	12
Jitters (NJitter)	30	30	30	30	30	30	30	30	30
Total time and efficiency									
Time including overhead (h)	338	343	364	364	180	51	51	54	54
Observing efficiency	.931	.917	.864	.864	.938	.931	.917	.864	.864

2.2 Observing requirements

We notice that the brightness of the Near-IR sky can vary strongly during the night, especially for J and likely also for Y. In the K-band, observations can be started by the time the sky is dark enough so the telescope can operate. The K-band sky brightness is sufficiently low around true sunset/sunrise, and hence observations can start well before astronomical twilight, if the telescope and ESO allows. The H-band sky behaves similarly, but it is known that the J-band sky continues to decrease strongly well after astronomical twilight, so for an optimal survey, these exposures are reserved for the middle of the night. The same probably holds for the Y band. *We request that ESO takes these considerations into account when planning for operations. The effectiveness of the telescope can be greatly increased if observations can start well before astronomical twilight and continue after astronomical sunrise.*

As we describe below, the field will be the "ideal" standard star field after the first year, when we'll have fantastically good calibrated magnitudes of all sources suitable for calibration. Hence data taken during twilight can be used as calibration sequences.

All observations will be taken using the following strategy. The observations will be split up in Observing Blocks of 1 hour, exposing a single pawprint. Jitters in a box of 30 arcsec will be used to allow for the correction of bad pixels, cosmic rays, structure in the dark, and reliable sky subtraction. These 1-hour observations will be straightforward to reduce. Three sequential Observing Blocks offset vertically by 1/3rd of a detector width will be executed to obtain full coverage of a column in a single band, and after that, the filter will be changed. This process will build up a homogeneous dataset over the years of the survey.

3 Survey data calibration needs

Bias, flat, dark and illumination correction frames from the VISTA calibration plan v1.4 is fully sufficient for our needs.

The narrow band filter images will require the same procedure as the broad band filters for bias and dark current subtraction. Flatfielding may be more challenging because of the combination of low throughput, potentially stronger effect of fringing and a photometric zeropoint which varies across the field because of the shifting bandpass. If necessary, a fringing correction will be applied to both twilight and domeflats by Fourier filtering of appropriate scales. Illumination correction will be essential after such filtering. The mesostep procedure (see 4.8) will be the main strategy for the narrow band images. Illumination correction as well as the photometric zero points including color terms will be obtained from such data.

For the broad bands photometric calibration only needs to be done about once per year as we observe the same field through out the survey. In addition, we note that the COSMOS field in itself will be a standard field - at least after the first year of our survey. Hence, there is no need to observe standard star fields several times per night as described in Sect. 5.4 of the v1.4 VISTA calibration plan. For the calibration of the narrow band observations we will observe spectrophotometric standard stars once per year.

Obtaining a good illumination correction is very important for clustering studies. We plan to

take special calibration sequences on the field for cross checks:
(i) take a sequence by stepping the camera over 10x10 arcmin, with 1 arcmin steps
(ii) take sequences by rotating the camera 90 and 180 degrees, and
(iii) obtain a sequence by moving the camera by a full detector separation in the horizontal direction, and 1/3 separation in the vertical direction.
This only needs to be done once during the survey. It will allow a direct consistency check of the illumination correction obtained from the normal calibration process. Once the illumination correction is established, the field is "self-calibrating"

The astrometric calibration will be tied to the general COSMOS astrometry which is defined by CFHT Megacam images (see more under Sect. 4).

4 Data reduction process

The data reduction will be spread over two systems:

1) CASU will do the basic processing (pre-processing, background subtraction, correction for non-linearity, detector effects, etc). This will deliver series of 2 minute integrations, which are NOT interpolated onto a new astrometric frame (but will contain astrometric information in the headers). This processing is provided as part of the VDFS, the VISTA Data Flow System. The work is located at CASU, Cambridge University.

2) the Astro-Wise infrastructure will be used to
a) do quality control of the delivered processed 2minutes images b) map the images onto a single astrometric frame, remove remaining artefacts, cosmic rays, c) combine the images into stacks

All participating nodes (Leiden-Groningen, Marseille-Terapix, Copenhagen) will be nodes of Astro-Wise. Astro-Wise will provide a system with distributed data storage and processing, and is very suitable for this survey.

Fig. 2 gives the block diagram showing all processing steps. We have to add that the details of these steps as they will be applied at CASU may change once real VISTA data becomes available.

The background subtraction is the step which may require most attention. Our experience with ultra deep VLT ISAAC imaging has shown that special care will need to be taken to make sure that the background subtraction is not the limiting factor towards reaching the desired depth. However, our experience has also shown that once the background looks good in the individual 2-minute images, and in the 1 hour stacks, it will not impose difficulties later on when averaging stacks.

It is foreseen that the background subtraction requires masking of the sources in the final image, to reduce artefacts. As we re-observe the same field again and again, this can be a fixed mask.

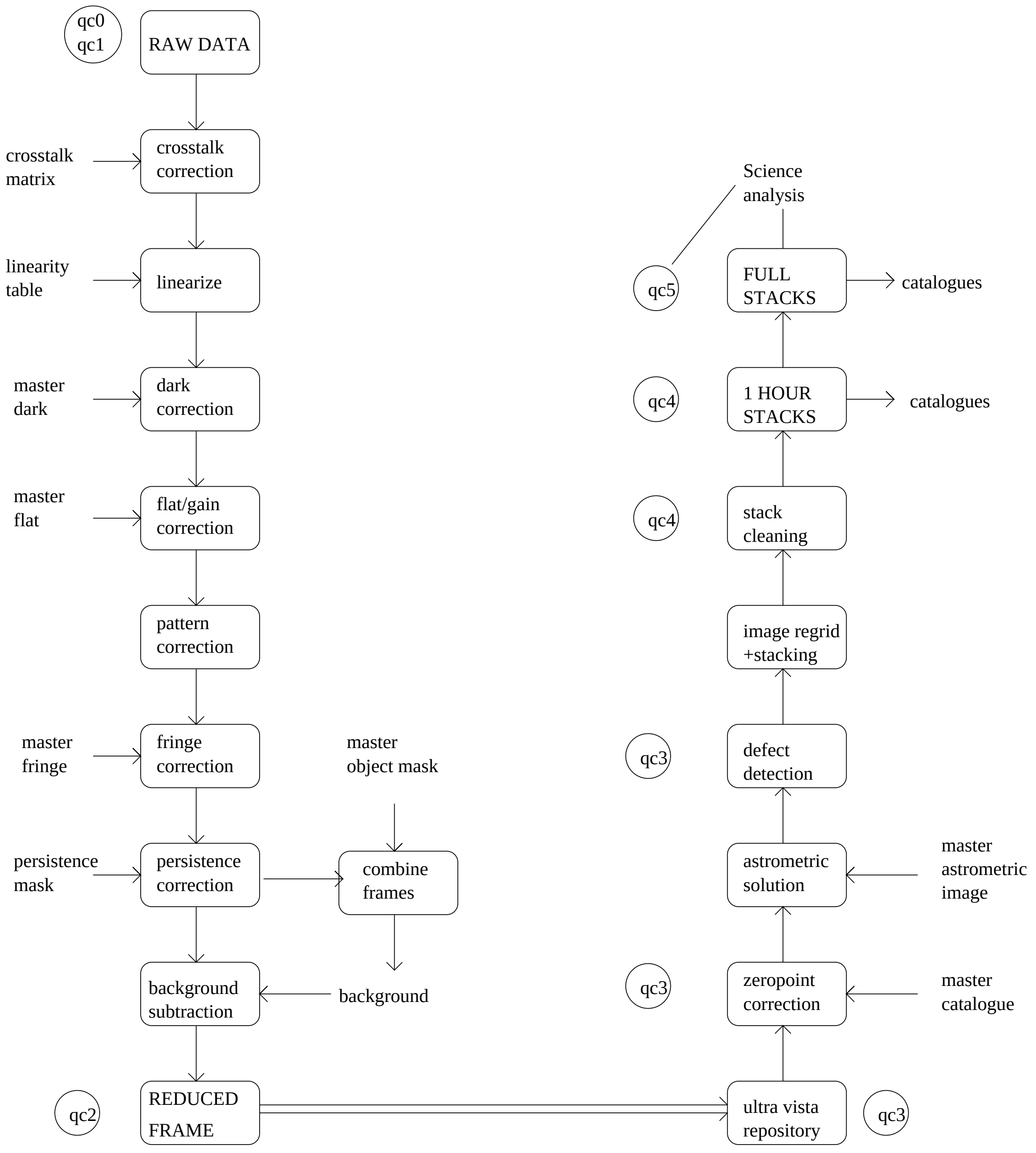

Fig 2. The basic processing steps of the ULTRA VISTA data. The left hand side indicates the steps taken at CASU, the right hand side indicates the steps taken within the Astro-Wise nodes. The quality control steps are indicated by circles and the different levels are numbered (see section 6).

We note that, since we keep re-observing the same field, we will produce images which are astrometrically identical, i.e., they cover exactly the same area on the sky. Hence they only need to be co-added to produce the final image.

The narrow-band data will require additional reductions due to a small passband shift over the field. We plan to get access to science commissioning data for the VISTA narrow-band filter in order to investigate and prepare for the special corrections that may be necessary in the data reduction. However, experience from ISAAC narrow band imaging with a narrow band filter at the same wavelength show that there should be no fundamentally different steps needed for the narrow band data (see Cuby et al. 2006, A&A in press, astro-ph/0611272).

The final quality control for the CASU processed data will take place in Leiden, Heidelberg, Terapix and Marseille.

5 Manpower and hardware capabilities devoted to data reduction and quality assessment

5.1 Management Structure

The UltraVista survey is conceived as a product resulting from the collaboration of 4 main nodes (Copenhagen, LAM-Marseille, Leiden, ROE). Each node has a local Principal Investigator and a Project Manager. The PIs act together in the project board. Active scientists are members of the Science Team, which meets at least three times a year, hearing the reports from topical working groups, in particular in data reduction and quality assessment.

The data flow has been defined to enable parallel processing at various sites as described in section 4. The work sharing described below assumes that the VISTA Data Flow System (VDFS) at CASU in the UK will will give access to the raw data and will deliver images corrected for background/sky. The processing of the complete dataset to produce assembled mosaics and source catalogs will then be performed under the Astro-Wise organisation with the Terapix and Leiden centers as the key nodes, supported by the Marseille team for multi-color catalog management.

The management structure of the project is indicated in Figure 3

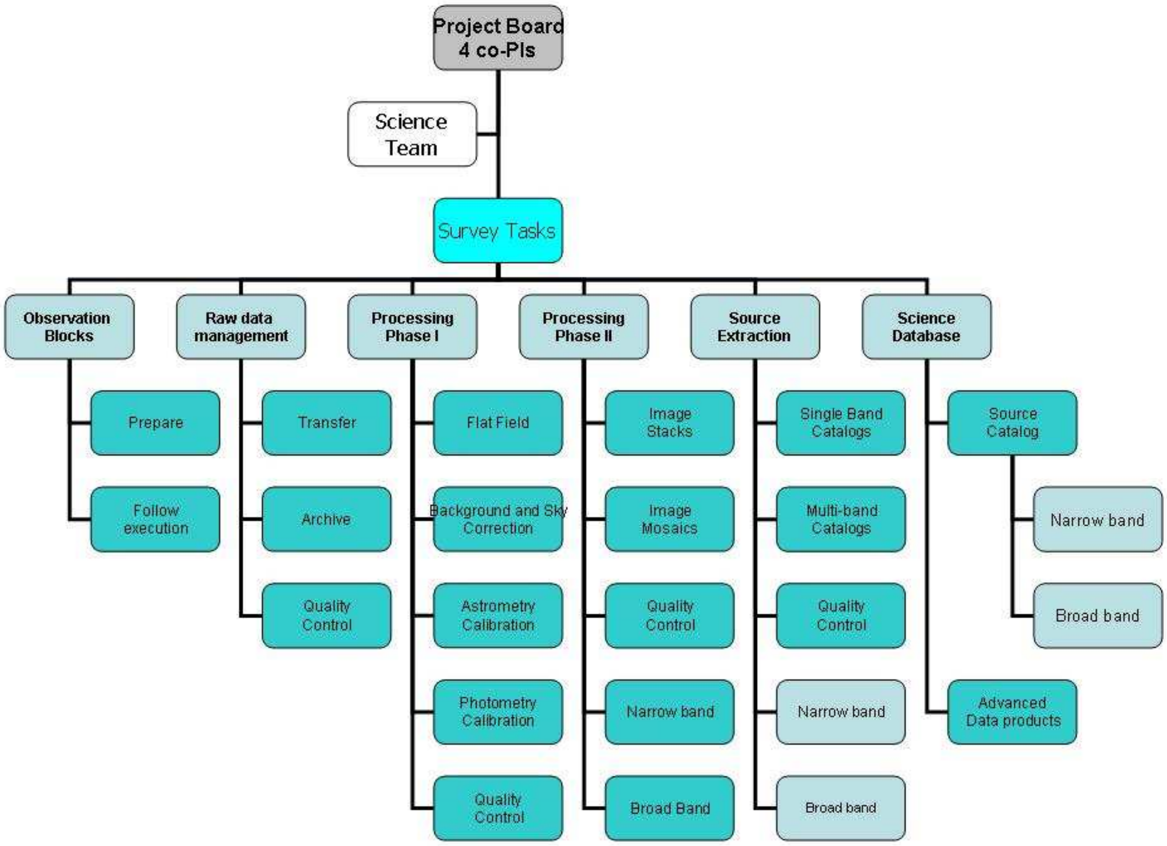

Fig. 3. Management structure of ULTRA-VISTA

5.2 Team members:

The team members are located at 8 different sites. We list below the experience and commitment to the survey of each of the sites.

Copenhagen	co-PI: Johan Fynbo
Yearly FTE commitment:	1.5
Relevant experience:	Narrow band surveys in the optical and near-IR
Tasks:	Narrow band Observing Blocks Narrow band catalogs
Scientific focus:	The highest redshift Lyman-α emitting galaxies

LAM - Marseille	co-PI: Olivier Le Fèvre
Yearly FTE commitment:	2
Relevant experience:	Large imaging surveys: CFHT-12K, CFHTLS, COSMOS-HST, WIRDS (NIR); Large spectroscopic surveys: VVDS, zCOSMOS; deep narrow band surveys
Tasks:	Broad band Observing Blocks Quality Control; Multi-band source catalogs: broad band and narrow band; Science database
Scientific focus:	Evolution of galaxies and large scale structures; evolution of the mass selected galaxies; evolution of the clustering of galaxies; highest redshift galaxies spectroscopic follow-up

Leiden	co-PI: Marijn Franx
Yearly FTE commitment:	2
Relevant experience:	ultra deep near-IR imaging, processing and analysis very high redshift galaxies, mass selected galaxies
Tasks:	Broad band Observing Blocks Processing Phase I and II
Scientific focus:	very high redshift galaxies, mass selected galaxies spectroscopic followup (VLT/JWST)

ROE - Edinburgh	co-PI: James Dunlop
Yearly FTE commitment:	2
Relevant experience:	Deep near-infrared surveys including UKIDSS UDS PI of SHADES submm survey + SCUBA2 Cosmology Survey Multi-frequency surveys, including optical and radio
Tasks:	Broad band observing blocks Quality control Independent source catalogue confirmation
Scientific focus:	Highest redshift galaxies and galaxy evolution Cosmological evolution of galaxy mass function Galaxy mass density + connection to theory Host galaxies of sub-mm sources Obscured AGN and their evolution

CASU	co-I: M. Irwin
Yearly FTE commitment:	0.6
Relevant experience:	Near-IR and optical imaging data processing
Tasks:	Processing of raw data into reduced basic frames
Scientific focus:	Local universe, variable objects

IAP - Paris	co-I: Yannick Mellier
Yearly FTE commitment:	1
Relevant experience:	Terapix processing center for large astronomical images; Large imaging surveys: CFH-12K and CFHTLS, WIRDS (NIR)
Tasks:	Processing Phase I and II Quality control
Scientific focus:	Evolution of the clustering of galaxies Weak lensing

MPIA - Heidelberg	co-I: Hans-Walter Rix
Yearly FTE commitment:	1.5
Relevant experience:	Processing of optical near-IR surveys Studies of distant galaxies, etc
Tasks:	Quality control matched multicolor catalogues
Scientific focus:	Very high redshift galaxies, studies of mass selected galaxies, AGN spectroscopic follow-up (LBT)

Omegacen - Groningen	co-I: Edwin Valentyn
Yearly FTE commitment:	0.5
Relevant experience:	Processing of surveys, distributed computing
Tasks:	Software development and support Survey support
Scientific focus:	galaxies in intermediate density environments

ESO	co-I: Palle Møller & Wolfram Freudling
Yearly FTE commitment:	1.0
Relevant experience:	Narrow band surveys
Tasks:	Narrow-band pipeline processing
Scientific focus:	High redshift galaxies and AGN

5.3 List of tasks and available hardware

The main tasks are listed in Table 5.3

Tasks	Responsibles
Observing Blocks: Broad Band	Leiden, Marseille
Observing Blocks: Narrow Band	Copenhagen
Raw data management	CASU, ESO, Leiden
Processing Phase I	CASU
Processing Phase II	IAP, Leiden
Processing Phase II Narrowband	Copenhagen, ESO
Source extraction: broad band	Heidelberg, Leiden, Marseille
Source extraction: narrow band	Copenhagen, Marseille
Multi-wavelength matching	Leiden
Science Database	Marseille

Each site has access to dedicated servers with large disc space. Furthermore, new hardware will be purchased before the start of the observing program to offer the latest processing power, memory and disc space.

The total volume of raw data will be $\simeq$ 7 Tb for 4 broad bands and one narrow band, this will be stored at CASU, and on the Astro-Wise system (Leiden node).

The processed basic images will occupy more space, $\simeq 14Tb$. The 1-hour stacks will occupy $\simeq 1Tb$. These will be made available for ESO for the public release.

6 Data quality assessment process

Data quality control will be one of the most important tasks. We have indicated in Fig. 2 the various levels of quality control:
qc0 + qc1: Quality control at Paranal, and at ESO, of the raw frames. These steps help ensure that the frames contain data.
qc2: Quality control at CASU, of the processed basic images (the individual 2-minute integrations). CASU will do quality control on a night-by-night basis, monitoring the stability of the sky, and taking samples of the processed data.
qc3: Quality control by ultra-vista on the processed basic images. As we re-observe the same field over and over again, we know well what to expect. Hence by comparing and differencing the basic images and catalogues with reference images and catalogues, we can establish quality (and problems). Various tools are available within Astro-Wise for this purpose. One of the important issues in this step is background subtraction. Residual gradients can limit the depth of the data, and may require feedback to CASU concerning the processing. For this analysis we also wish to have direct access to the raw data itself. This will allow fast flagging, and tracking of problems/artefacts.
qc4: The 1-hour stacks of the basic images will undergo extensive quality control. Again, we will use our a priori knowledge of the field, and visual inspections of the stacks are critical to establish quality.
qc5: The full stacks are the end product of the data processing sequence, and will undergo extensive quality control. As they will produce the reference images needed for steps qc3 and qc4, they are important for this process.

The catalogues made from the full stacks are another important diagnostic. We request to obtain the full raw data on the astro-wise system (Leiden node). This is expected to significantly accelerate the quality control and feedback loop for background subtraction.

7 Data product and VO compliance:

We plan to make the first data release 1 year after the end of the first observing season. Thereafter we plan further, annual data releases.

We will provide standard flat-file image and catalogue data to the ESO science archive facility, comprising:

1. Instrument corrected, sky-subtracted, photometrically and astrometrically calibrated 1-hour images.
2. Full co-added images using all data obtained up to the release, along with corresponding weight maps.
3. Multi-parameter, single-band catalogues derived using the SExtractor software.
4. Y, J, H, K band-merged catalogues (on a longer timescale, as merited by survey progress).

The meta-data supplied within these self-describing FITS files will facilitate VO compliance. In addition these flat files will be accompanied by an .xml registry descriptor file, containing unified content descriptors. This will allow the production of generic search tools at the ESO archive.

8 Timeline delivery of data products to the ESO archive:

We anticipate that the survey will start in around January 2008, i.e. in period 80. This time we refer to as T0. The field can be observed throughout the remaining period 80 (292 hours) and for about 68 hours in period 81.

We first complete the deep survey and then carry on with the ultra- deep survey. For the ultra-deep survey we will build up the signal-to-noise ratio in parallel in the four broad band filters and the narrow band filter. The deep survey can be completed in P80/81. The ultra-deep survey can be started in P80/81, but it will not reach significantly deeper limits than the deep survey before P82/83.

The timeline looks like this:

T0: start of observations. Homogeneous coverage of the full area to the depth of the wide survey. Start of ultra-deep survey.
T1: delivery of last raw data of the first observing season (T0 + $\approx 5 - 6$ months, near middle of P81)
T1+12months: release of the fully reduced data and catalogs for the deep wide survey from P80-81 season.

T1+24months: release of the fully reduced data from the ultra-deep survey data from observing seasons 80/81 and 82/83.

Thereafter we expect that we can deliver science products to ESO within 1 year after the observations have been done for the remaining years of the survey (i.e. until after P90).