1 Title: The VISTA Extragalactic Infrared Legacy Survey (VEILS)

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1.1 Abstract

The VISTA Extragalactic Infrared Legacy Survey (VEILS), is a deep J and K_S transient and wide-field survey with the primary goals of understanding the epoch of reionization, the build-up of massive galaxies and constraining the cosmological equation of state using Type 1a supernovae and AGN dust lags. VEILS will cover 9 sq-deg of the extragalactic sky over three fields: ES1 (RA = 00h 30m; Dec = -43d 00m), CDF-S (RA = 03h 36m; Dec = -28d 00m) and XMM-LSS (RA = 02h 22m; Dec = -06d 00m). The proposed per-epoch survey depths are J <23.5 and K_S < 22.5 in all fields and we expect a total of 33-50 epochs per field per filter over the entire duration of the survey. We request a total of 1153 hours (128 nights) in <1.1" seeing conditions to complete the survey.

2 Survey Observing Strategy

2.1 Scheduling requirements

VEILS will cover 9 sq-deg of the extragalactic sky over three fields: ES1 (RA = 00h 31m; Dec = -43d 00m), CDF-S (RA = 03h 36m; Dec = -28d 00m) and XMM-LSS (RA = 02h 22m; Dec = -06d 10m). As the fields are concentrated around 00h < RA < 04h, the scheduling of these observations is most heavily subscribed around October to December. The Call for Proposals for Public Surveys with VISTA indicated that the new VISTA Public Surveys would begin in Period 98 (October 2016). However, we now understand that the majority of observations will begin in Period 99 (March 2017) and continue until Period 103 (Sept 2019). The proposed VEILS survey strategy, and particularly the cadence requirements for the survey, mean VEILS currently takes up most of the available time in RA bins 00h to 04h in each semester. Given our original time allocation for 1179 hours (131 nights) as per our survey proposal, we therefore highlight two alternative survey strategies below:

(A) Assuming six semesters of observing from Period 99 to Period 104 for a total time request of 1153 hours (128 nights). Note - observations of one of the ES1 fields is beginning in Period 98 due to the availability of time at RA∼0 hrs in this semester.
(B) Assuming five semesters of observing from Period 99 to Period 103 for a reduced time request of 971 hours (108 nights). Note - observations of one of the ES1 fields is beginning in Period 98 due to the availability of time at RA∼0 hrs in this semester.

Each of the three VEILS fields covers 3 sq-deg or 2 pointings of the 1.475×1.2005° VIRCAM camera. The pointings are chosen so as to provide maximal overlap with existing and upcoming optical data from the Dark Energy Survey (DES), HyperSuprimeCam (HSC) and Large Synoptic Survey Telescope (LSST) projects, as well as mid infra-red data from the *Spitzer* DeepDrill Survey. These pointings also ensure that a contiguous region of sky has been imaged in the near infra-red when combining VEILS with the current VIDEO survey. We have checked that suitable guide stars are available (based on the 2MASS catalogue in SADT v5.1.0) in these pointings. The six VEILS pointing centres together with the position angle of the camera for each of these pointings, is given in Table 1.

The scheduling is primarily driven by the transient science case which requires cadencing of ∼14 days in both the J and K_s bands for the supernovae (SNe) light-curve and AGN dust lag measurements. Accounting for the observability of the fields in each semester, we envisage 5, 6 and 8 epochs in the CDFS, XMM-LSS and ES1 fields

Table 1: Summary of the six VEILS pointings over three extragalactic fields

Field	R.A.	Dec	P.A
CDFS-Wide1	03:36:07.75	−26:44:59.6	0
CDFS-Wide2	03:36:07.78	−29:17:02.0	0
XMM-Wide1	02:24:30.14	−06:09:59.4	90
XMM-Wide2	02:20:00.07	−06:07:10.2	90
ES1-Wide1	00:31:23.14	−42:35:01.7	0
ES1-Wide2	00:31:23.16	−43:40:01.9	0

respectively in the odd semesters and 9, 8 and 8 epochs in the CDFS, XMM-LSS and ES1 fields respectively in the even semesters. The cadencing will be achieved using time constraints on the OBs and time-link containers within P2PP.

2.2 Observing requirements

The VEILS observing strategy is summarised in Table 2. Our goal is to achieve per-epoch SNR=5 for $K_s = 22.5$ mag and $J = 23.5$ mag point sources, respectively, assuming an average of $1''$ seeing. This will require 1920 s per-pixel exposure time. In the standard tiling strategy, 6 pawprints are required to fully image a single VIRCAM tile with each pixel being observed at least twice (except for a small stripe at the edge of the tile). The per pawprint exposure time is therefore 960 s.

We adjust the observing strategy from the original proposal to fit the observations in OBs of approximately 1 hour in length. In J we will observe with DIT=30s, NDIT=2, NJITTER=16, NEXP=1, and in K_s we will use DIT=10s, NDIT=8, NJITTER=12, NEXP=1. Instead of observing all 6 paw-prints within one OB to create a full tile, we will split the tile into 2 OBs with the *VIRCAM_img_obs_tile3* template and use the patterns *Tile3nx* and *Tile3px*, respectively, to fill the whole tile. A random jitter pattern will ensure reasonable accuracy is obtained in the sky subtraction for each 3-paw half-tile.

Each J band OB will take 1h 3m (3780s) to execute and each K_s band OB will have a total execution time of 1h 7m (4020s).

For the cadencing, we will make use of time-link containers. We will create N OBs per semester for each filter and each half-tile, where N corresponds to the total number of epochs for that observing season for a given pointing. The N OBs will be grouped into a time-link container with the first OB (corresponding to the first epoch) in each semester having an absolute constraint on the start date of observations. All subsequent OBs in each semester will then have time constraints of within 10-18 days of the previous OB. Setting the same time constraints on both the J and K_S band OBs will also ensure that both filters have roughly the same number of epochs at the end of each semester, and therefore that the co-add data in the two filters will always be of comparable depth as the survey progresses. We understand that with such an observing strategy, the time associated with any failed epochs will be compensated by ESO.

14-16 epochs (an epoch every 14 ± 4 days) are required per year per field for the transient science. The ES1 field is equally well observed in both semesters and will therefore require at least 8 epochs per semester. The XMM-LSS and CDF-S fields are more visible in the even semesters so the observing will be split into 8 and 6 epochs in the even and odd semesters for XMM and 9 and 5 epochs in the even and odd semesters for CDFS.

In October 2016 we were informed by ESO of an opportunity to observe one of the ES1 fields in Period 98. To maximise the early science return from these observations, 10 epochs of observations of the single ES1 field have been submitted as part of P98. Consequently, we do not require observations of one of the ES1 fields in the last semester of VEILS observations. The breakdown per semester is shown in Tables 3, 4 and 5 for each field. While there are no moon constraints for these observations, J-band data should be taken at least 60 minutes after twilight.

Table 2: Summary of observing strategy.

Field	Ntiles	N OBs per epoch	Filter	DIT×NDIT	NJITTER	NEXP	Nepochs over 3 yrs (2.5 yrs)
CDFS	2	4	J	30s×2	16	1	42 (33)†
ES1	2	4	J	30s×2	16	1	48-50 (40-42)†
XMM	2	4	J	30s×2	16	1	42 (34)†
CDFS	2	4	K_s	10s×8	12	1	42 (33)†
ES1	2	4	K_s	10s×8	12	1	48-50 (40-42)†
XMM	2	4	K_s	10s×8	12	1	42 (34)†

†The number of epochs corresponds to Survey Strategy A (i.e. six semesters of observing) and the number in brackets corresponds to Survey Strategy B (i.e. five semesters of observing).

Exposure Times & Final Co-add Depths: The cumulative number of hours per pixel expected from the proposed survey strategy above as well as the expected final co-add depths in the J and K_S bands estimated using the ESO VIRCAM Exposure Time Calculator (v6.0.0) are given in Table 6 for both survey strategies - A and B.

3 Survey data calibration needs

Standard calibrations taken as part of VISTA operations are sufficient for the calibration of the VEILS data. The data calibration steps are detailed below together with information regarding the standard calibration files to be used in each case:

3.1 Detector Characteristics:

Basic instrument calibration frames (dark frames, reset frames, dome flats and linearity calibration, twilight flats), will be available as part of the VISTA standard operating procedure, mainly from daytime and twilight procedures. As has been done for the current VISTA public surveys, these files will be used for characterising the properties of the detectors and removing instrumental signatures from the data.

3.2 Astrometry:

Astrometric calibration will be performed by matching a catalogue of bright unsaturated stars in each VIRCAM frame to 2MASS using the approximate pointing information in the FITS headers as a starting point.

The WCS distortion model used for VISTA is based on the ZPN projection. For a purely radial distortion, as expected for VISTA, this relates the true on-sky radial distance from the optical axis to the measured radial distance in the focal plane:

$$r' = k1 \times r + k3 \times r^3 + k5 \times r^5 + ... \tag{1}$$

where $k1$ is the plate scale at the centre, and $k3$, $k5$ etc.... describe the distortion relative to the angular distance on the focal plane. For VISTA $k1$ = 0.3413 arcsec/pixel (i.e. 17.065 arcsec/mm) and in angular units the distortion coefficients are given quite accurately by k3/k1 = 44 and k5/k1 = -10300 (using angular measures in radians). Higher order terms seem to be negligible.

After distortion correction the residuals from individual detector linear fits can be used to monitor the quality of the 2MASS-based astrometric solution. Based on the performance of current VISTA surveys, over the whole

Table 3: Scheduling plan and observing requirements for the ELAIS-S Field.

Period	Target name	RA	DEC	Filter setup	Tot. exp. time [hrs]	Tot. exec.[1] time [hrs]	Seeing/FLI/ transparency
P98	ES1-Wide1	00h	−42	J	16.0	21.0	1.2"/bright/THN
P98	ES1-Wide1	00h	−42	K_S	16.0	22.3	1.2"/bright/THN
Total time for P98						**43.3**	
P99	ES1-Wide1	00h	−42	J	12.8	16.8	1.1"/bright/THN
P99	ES1-Wide1	00h	−42	K_S	12.8	17.9	1.1"/bright/THN
P99	ES1-Wide2	00h	−43	J	12.8	16.8	1.1"/bright/THN
P99	ES1-Wide2	00h	−43	K_S	12.8	17.9	1.1"/bright/THN
Total time for P99						**69.4**	
P100	ES1-Wide1	00h	−42	J	12.8	16.8	1.1"/bright/THN
P100	ES1-Wide1	00h	−42	K_S	12.8	17.9	1.1"/bright/THN
P100	ES1-Wide2	00h	−43	J	12.8	16.8	1.1"/bright/THN
P100	ES1-Wide2	00h	−43	K_S	12.8	17.9	1.1"/bright/THN
Total time for P100						**69.4**	
P101	ES1-Wide1	00h	−42	J	12.8	16.8	1.1"/bright/THN
P101	ES1-Wide1	00h	−42	K_S	12.8	17.9	1.1"/bright/THN
P101	ES1-Wide2	00h	−43	J	12.8	16.8	1.1"/bright/THN
P101	ES1-Wide2	00h	−43	K_S	12.8	17.9	1.1"/bright/THN
Total time for P101						**69.4**	
P102	ES1-Wide1	00h	−42	J	12.8	16.8	1.1"/bright/THN
P102	ES1-Wide1	00h	−42	K_S	12.8	17.9	1.1"/bright/THN
P102	ES1-Wide2	00h	−43	J	12.8	16.8	1.1"/bright/THN
P102	ES1-Wide2	00h	−43	K_S	12.8	17.9	1.1"/bright/THN
Total time for P102						**69.4**	
†P103	ES1-Wide1	00h	−42	J	12.8	16.8	1.1"/bright/THN
†P103	ES1-Wide1	00h	−42	K_S	12.8	17.9	1.1"/bright/THN
P103	ES1-Wide2	00h	−43	J	12.8	16.8	1.1"/bright/THN
P103	ES1-Wide2	00h	−43	K_S	12.8	17.9	1.1"/bright/THN
Total time for P103						**69.4**	
†P104	ES1-Wide2	00h	−43	J	12.8	16.8	1.1"/bright/THN
†P104	ES1-Wide2	00h	−43	K_S	12.8	17.9	1.1"/bright/THN
Total time for P104						**34.7**	
Total time for ES1 Field						**425 (390.3)**	

† Observing Plan A only

Table 4: Scheduling plan and observing requirements for the CDF-S Field.

Period	Target name	RA	DEC	Filter setup	Tot. exp. time [hrs]	Tot. exec.[1] time [hrs]	Seeing/FLI/ transparency
P99	CDFS-Wide1	03h	−26	J	8	10.5	1.1"/bright/THN
P99	CDFS-Wide1	03h	−26	K_S	8	11.2	1.1"/bright/THN
P99	CDFS-Wide2	03h	−29	J	8	10.5	1.1"/bright/THN
P99	CDFS-Wide2	03h	−29	K_S	8	11.2	1.1"/bright/THN
Total time for P99						**43.4**	
P100	CDFS-Wide1	03h	−26	J	14.4	18.9	1.1"/bright/THN
P100	CDFS-Wide1	03h	−26	K_S	14.4	20.1	1.1"/bright/THN
P100	CDFS-Wide2	03h	−29	J	14.4	18.9	1.1"/bright/THN
P100	CDFS-Wide2	03h	−29	K_S	14.4	20.1	1.1"/bright/THN
Total time for P100						**78**	
P101	CDFS-Wide1	03h	−26	J	8	10.5	1.1"/bright/THN
P101	CDFS-Wide1	03h	−26	K_S	8	11.2	1.1"/bright/THN
P101	CDFS-Wide2	03h	−29	J	8	10.5	1.1"/bright/THN
P101	CDFS-Wide2	03h	−29	K_S	8	11.2	1.1"/bright/THN
Total time for P101						**43.4**	
P102	CDFS-Wide1	03h	−26	J	14.4	18.9	1.1"/bright/THN
P102	CDFS-Wide1	03h	−26	K_S	14.4	20.1	1.1"/bright/THN
P102	CDFS-Wide2	03h	−29	J	14.4	18.9	1.1"/bright/THN
P102	CDFS-Wide2	03h	−29	K_S	14.4	20.1	1.1"/bright/THN
Total time for P102						**78**	
P103	CDFS-Wide1	03h	−26	J	8	10.5	1.1"/bright/THN
P103	CDFS-Wide1	03h	−26	K_S	8	11.2	1.1"/bright/THN
P103	CDFS-Wide2	03h	−29	J	8	10.5	1.1"/bright/THN
P103	CDFS-Wide2	03h	−29	K_S	8	11.2	1.1"/bright/THN
Total time for P103						**43.4**	
†P104	CDFS-Wide1	03h	−26	J	14.4	18.9	1.1"/bright/THN
†P104	CDFS-Wide1	03h	−26	K_S	14.4	20.1	1.1"/bright/THN
†P104	CDFS-Wide2	03h	−29	J	14.4	18.9	1.1"/bright/THN
†P104	CDFS-Wide2	03h	−29	K_S	14.4	20.1	1.1"/bright/THN
Total time for P104						**78**	
Total time for CDF-S Field						**364.2 (286.2)**	

† Observing Plan A only

Table 5: Scheduling plan and observing requirements for the XMM Field.

Period	Target name	RA	DEC	Filter setup	Tot. exp. time [hrs]	Tot. exec.[1] time [hrs]	Seeing/FLI/ transparency
P99	XMM-Wide1	02h	−06	J	9.6	12.6	1.1"/bright/THN
P99	XMM-Wide1	02h	−06	K_S	9.6	13.4	1.1"/bright/THN
P99	XMM-Wide2	02h	−06	J	9.6	12.6	1.1"/bright/THN
P99	XMM-Wide2	02h	−06	K_S	9.6	13.4	1.1"/bright/THN
Total time for P99						**52**	
P100	XMM-Wide1	02h	−06	J	12.8	16.8	1.1"/bright/THN
P100	XMM-Wide1	02h	−06	K_S	12.8	17.9	1.1"/bright/THN
P100	XMM-Wide2	02h	−06	J	12.8	16.8	1.1"/bright/THN
P100	XMM-Wide2	02h	−06	K_S	12.8	17.9	1.1"/bright/THN
Total time for P100						**69.4**	
P101	XMM-Wide1	02h	−06	J	9.6	12.6	1.1"/bright/THN
P101	XMM-Wide1	02h	−06	K_S	9.6	13.4	1.1"/bright/THN
P101	XMM-Wide2	02h	−06	J	9.6	12.6	1.1"/bright/THN
P101	XMM-Wide2	02h	−06	K_S	9.6	13.4	1.1"/bright/THN
Total time for P101						**52**	
P102	XMM-Wide1	02h	−06	J	12.8	16.8	1.1"/bright/THN
P102	XMM-Wide1	02h	−06	K_S	12.8	17.9	1.1"/bright/THN
P102	XMM-Wide2	02h	−06	J	12.8	16.8	1.1"/bright/THN
P102	XMM-Wide2	02h	−06	K_S	12.8	17.9	1.1"/bright/THN
Total time for P102						**69.4**	
P103	XMM-Wide1	02h	−06	J	9.6	12.6	1.1"/bright/THN
P103	XMM-Wide1	02h	−06	K_S	9.6	13.4	1.1"/bright/THN
P103	XMM-Wide2	02h	−06	J	9.6	12.6	1.1"/bright/THN
P103	XMM-Wide2	02h	−06	K_S	9.6	13.4	1.1"/bright/THN
Total time for P103						**52**	
†P104	XMM-Wide1	02h	−06	J	12.8	16.8	1.1"/bright/THN
†P104	XMM-Wide1	02h	−06	K_S	12.8	17.9	1.1"/bright/THN
†P104	XMM-Wide2	02h	−06	J	12.8	16.8	1.1"/bright/THN
†P104	XMM-Wide2	02h	−06	K_S	12.8	17.9	1.1"/bright/THN
Total time for P104						**69.4**	
Total time for XMM Field						**364.2 (294.8)**	

† Observing Plan A only.

Table 6: Co-added survey exposure times for each of the survey fields in both filters.

Field	Filter	Cumulative hrs† per pixel	Depth† (5σ AB; point source)
CDFS	J	11.2 (8.8)	25.48 (25.36)
CDFS	K_S	11.2 (8.8)	24.53 (24.40)
XMM	J	11.2 (9.1)	25.49 (25.37)
XMM	K_S	11.2 (9.1)	24.54 (24.41)
ES1	J	12.8 (10.7)	25.57 (25.46)
ES1	K_S	12.8 (10.7)	24.61 (24.51)

†The numbers correspond to Survey Strategy A (i.e. six semesters of observing) while the numbers in brackets correspond to Survey Strategy B (i.e. five semesters of observing).

VIRCAM field-of-view the current first pass astrometric solutions achieve positions within 25 mas for the entire field. Without the k5 term, the systematic residuals increase to of order 50 mas near the edge of the field. Further refinement of the default astrometric model is being carried out by CASU but the current astrometric calibration seems sufficient for the science goals of VEILS. More details of the astrometric calibration and current astrometric performance can be found at `http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/astrometric-properties`

3.3 Photometric Calibration:

VISTA Photometry is on the VISTA system, which is tied to 2MASS and calibrated via colour equations between the two systems (see below). There is also now significant overlap on the sky between the VISTA VIRCAM surveys and the UKIDSS WFCAM surveys and appropriate colour terms between these datasets have also been derived.

Briefly the following steps are followed by CASU to calibrate a single VISTA pawprint:

1. All detectors are normalised to the same approximate gain using the flatfield exposures.

2. The catalogue of sources detected on each VISTA detector is crossmatched against the 2MASS catalogue (this is also used to refine the astrometric solution above).

3. The 2MASS/WFCAM magnitudes for all matching stars are converted to expected VISTA magnitudes using the colour equations (below), including terms to account for interstellar reddening. The VEILS fields are extragalactic, high-latitude fields so the galactic extinction is small.

$$J_V = J_2 - 0.065 \times (J - K_s)_2 \tag{2}$$

$$K_{sV} = K_{s2} + 0.010 \times (J - K_s)_2 \tag{3}$$

$$J_V = J_W - 0.019(\pm 0.006) \times (J - K)_W - 0.005(\pm 0.004) \tag{4}$$

$$K_{sV} = K_W + 0.004(\pm 0.011) \times (J - K)_W - 0.013(\pm 0.005) \tag{5}$$

4. The offset between the median 2MASS and VISTA magnitudes is the Zeropoint of the detector (corrected to airmass unity under the assumption of a default extinction value for the filter)

5. A single preliminary median (of all 16 detectors) Zeropoint is written to the FITS header (keyword: MAGZPT), while the scatter in the measurements (the median absolute deviation MAD*1.48, a robust estimate of the Gaussian sigma) forms a measure in the error in the Zeropoint (keyword: MAGZRR).

6. A final stage to the photometric calibration takes account of systematic differences between the 16 detectors, measured on a monthly basis. The residuals from all 2MASS stars used in the frame zero-point determination (i.e. J, H, Ks signal:noise >10:1) are also computed on a per pointing basis together with their standard coordinate location with respect to the tangent point of the telescope optical axis. The residuals are stacked and used to generate delta-Zeropoints per detector (the value of MAGZPT is actually updated for each detector).

The above photometric calibration steps should be sufficient for VEILS.

More details on the photometric calibration steps can be found at `http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/photometric-properties`.

3.4 Illumination Correction:

Although previous versions of the VDFS pipeline do not include illumination correction, by looking at the combined residuals of several years of data, a low level residual of up to 0.05 mag in the K_s band (but much smaller in bluer filters) has been detected. This residual has a clear and stable spatial structure, and it can be removed by generating a 2D map on detector coordinates. This effective illumination correction is expected to be applied by CASU to future versions of the processed VISTA data, and it is anticipated that the first VEILS data release will therefore incorporate such an illumination correction.

4 Data reduction process

4.1 Pipeline Processing:

The Cambridge Astronomical Survey Unit (CASU) are responsible for the VDFS pipeline processing component which has been designed for VISTA imaging and scientifically verified by processing data from all the current VISTA public surveys and all the PI surveys using VISTA. The standard processing includes instrumental signature removal - bias, non-linearity, dark, flatfielding, destriping, sky background removal and homogenisation during image stacking and mosaicking (See Fig. 1). The standard catalogues that are generated include astrometric, photometric, shape and DQC information. These catalogues are used for astrometric calibration performed through an appropriate World Coordinate System (WCS) and photometric calibration from 2MASS recorded in all FITS headers. An internal photometric ubercal is used to further improve the differential photometry over the field based on single epoch-to-epoch matching. Systematics over the full field-of-view are controlled by stacking both astrometric and photometric residuals on a monthly cycle corresponding to the flatfield and linearity updates. CASU also provide propagated image error arrays via confidence maps, realistic errors on selected derived parameters, nightly extinction measurements via photometric zeropoint sequences in relevant passbands, pipeline software version control and processing history including calibration files all recorded in the FITS headers together with the final assigned ESO grades.

4.2 Science Archives:

The data reduction and catalogue production process will make use of several archive facilities. The VISTA Science Archive (VSA) at the Wide Field Astronomy Unit (WFAU, Edinburgh) will ingest the reduced tiles and catalogues produced by CASU into their database accessible through the VSA web-based interface. VEILS data will be combined with public VIDEO data over the same fields and released. The VSA therefore serves as an archive facility both internally within the VEILS collaboration as well as to the larger astronomy community. A science archive facility is also provided by L. da Costa and the Brazil group (currently being used for the DES Collaboration), which can be used for additional data quality control. Finally, a database and archive facility exists in Cambridge and will be used for the final data quality assessment (led by E. Gonzalez-Solares) before Phase 3 delivery of the data to ESO.

4.3 Static Data Processing by VEILS Team:

For the extragalactic static science goals of the survey, survey-specific sky-subtraction and stacking of individual frames will need to be carried out. Deep object masks will be created and iteratively used to improve the single epoch sky subtraction. This will be done using the pipeline currently in operation for the VIDEO survey (led by M. Jarvis using resources at Oxford). Catalogue production will be carried out independently at Oxford and Cambridge by running both the SExtractor and Imcore source extraction codes. The focus at Cambridge will be the combination of the IR data with optical survey datasets as they become available. Both the co-adding and source extraction pipelines are already in operation at Oxford and Cambridge. Finally Banerji, Bowler, Jarvis and Muzzin, together with PhD students working under their supervision, will also be responsible for quality control and validation of the static data products for example by using them for the calculation of galaxy photometric redshifts.

4.4 Transient Data Processing by VEILS Team:

The transient science goals require analysis of individual images to produce light curves of supernovae and AGN, and potentially to identify new infrared transients. Efforts in this field will be concentrated in Southampton. During 17/18, we will use the DES real-time transient pipeline to locate optical transients in the DES overlap fields via links from M. Sullivan, M. Childress, M. Smith. M. Childress is also developing a pipeline to run on, and locate transients in, VISTA data. If DES has to be replaced by a VEILS-supporting optical survey with the VST from 2018/19 onwards, M. Childress will run his realtime reduction and image subtraction pipeline to identify unknown transients and locate supernovae in this VST data. This pipeline is currently being built and trained on VIDEO data. Full science-ready light curves will be extracted by M. Smith, M. Sullivan (supernovae), B. Boulderstone, and S. Hoenig (AGN) from the fully calibrated CASU single-epoch data, using existing pipelines. Quality will be assessed by differential photometry of field stars at all epochs, with a S/N dependent figure-of-merit being extracted based on the stability of the photometry over the whole survey.

5 Staff commitment and hardware capabilities devoted to data reduction and quality assessment

In Table 7, we summarise the securely funded FTE commitments distributed over the different tasks. Further FTEs will be sought through Southampton and Cambridge STFC consolidated grant proposals submitted in February 2017-2018.

The PI (M. Banerji) has recently been appointed to a five year senior research fellowship position (funded until December 2020) and will therefore be able to dedicate a significant fraction of time (0.4 FTE per year) to the management and running of the VEILS survey. An STFC funded PhD student (starting October 2017) is also expected to dedicate 100% of their time to VEILS. Funding will be sought from STFC for a dedicated VEILS postdoctoral researcher who will focus on producing co-added images and catalogues, combining these with optical datasets e.g. from DES and exploiting the multi-wavelength data for high-redshift science. The VHS PI (McMahon) and VHS postdoctoral researcher (already funded by STFC) will contribute 0.2 FTE per year, mainly in terms of adapting the current VHS Data Quality Control scripts and Phase 3 delivery scripts for use by the VEILS team. In addition to this, the Oxford group (Jarvis, Bowler, VIDEO PDRA) will contribute 0.7 FTE per year towards data reduction, analysis and quality control of the final stacked images and catalogues. Several other groups listed in Table 7 have also committed to devote at least 0.1 FTE per year each to catalogue verification.

The Co-PI (S. Hoenig) is part-funded through an ERC Starting Grant for the next five years, which reserves 0.2 FTE per year for science related to AGN cosmology. Current 4-year PhD student B. Boulderstone, as well as a new ERC-funded student, will dedicate 0.5 FTE per year each on near-IR photometry/variability of AGN. M. Sullivan's ERC provides for funding on supernova cosmology until May 2019, of which 0.2 FTE of his personal time can be committed to VEILS light curve extraction and science. Beyond May 2019 we will seek support from STFC. M. Smith (funded by M. Sullivan's ERC) is already running a small VEILS-type supernova survey with VISTA (097.A-1039) and has all required data extraction, analysis, and quality control tools in hand. He will fully commit his expertise to VEILS and the DES overlap (1.0 FTE). M. Childress (0.2 FTE) will be responsible for identification of new infrared transients in the VEILS data and link the detection to optical data from DES. In the event DES supernova science will not be extended beyond 2017, we will request complementary VST data, which will also be processed through Childress' realtime analysis software.

The pipeline processing will primarily be carried out by CASU and based on experience with current VISTA surveys, the contribution is expected to be 2 FTE for data processing, quality control, reprocessing after major bug fixes and/or enhancements, system maintenance and upgrades. This is for all VISTA surveys over the entire duration of these surveys. However, we note that many of these tasks are common to all the VISTA surveys so the total FTE does not need to be divided equally between the surveys. Hardware CPU requirements for the Cambridge processing pipeline are specified to have an overcapacity of a factor of at least 3. Data storage will be purchased as required and all raw and processed files will be stored using lossless Rice compression to save a factor of 4 in hardware storage requirements.

WFAU have 2.4 FTE (funded until March 2019) for development, operations and management of the VSA across all the VISTA surveys. We therefore estimate 0.5 FTE for VEILS from the WFAU. It is estimated that the total hardware requirements for storage of VEILS data at the VSA will be $\sim$5 TB for flat file storage and $\sim$1 TB for database storage, after combining VEILS with VIDEO data in the same fields. These storage requirements are already covered by the current WFAU grant.

6 Data quality assessment process

The data quality assessment procedure and data reduction and delivery plan will follow the same procedures as are currently successfully in operation for the ongoing VISTA Public Surveys. Namely, the Cambridge Astronomical Survey Unit (CASU) are responsible for pipeline processing and will carry out the first data quality assessment via a local Data Quality Control (DQC) database that is already in operation in Cambridge. Survey-specific frame-stacking will be carried out in Oxford using infrastructure already in place from the VIDEO survey. The stacked images will be used for catalogue production at Cambridge (led by Banerji) and Oxford (led by Jarvis and Bowler). Stacked products will be delivered to the Wide Field Astronomy Unit (WFAU) in Edinburgh as well as the Brazil Portal for further data quality control. Finally, the stacked images and catalogues will be delivered to ESO by Gonzalez-Solares following another round of data quality assessments using the local database in Cambridge. The Phase 3 delivery follows the same procedures as are currently in operation for VHS.

The pre-stacked, calibrated images will also be processed by the members of the transient team (Hoenig, Sullivan, Smith, Boulderstone, Childress) in Southampton to extract SNe and AGN light curves, using the computational infrastructure that has already been set in place. This consists of two high-performance servers with 40+ cores each. M. Childress will be responsible for running a difference imaging pipeline on the VEILS data to produce a catalogue of transients. Quality will be assessed by producing differential photometry light curves of field stars at different brightnesses. These stars will be tracked throughout the survey and their photometric stability (deviation from the mean) at each epoch is used as a measure of S/N-dependent light curve data quality. These measures will be provided in the Level 3b data products (see below).

7 External Data products and Phase 3 compliance

VEILS is a diverse survey with both static and time-domain aspects. Therefore, several types and levels of data products will need to be delivered. Our main data products will be:

- *Level 1 data package:* Our lowest level data products will consist of **fully reduced tile images at both wavebands for each epoch**. Processing will start at the raw data frames and include instrumental corrections for each paw print, combination of the dithered images and standard calibration (flat fielding and dark correction). The images will be supplied with the **full-tile calibration data** as well as **statistical confidence maps** for each tile and supplied together with **single band source lists**. Header keywords will be propagated from the raw files and amended with calibration information. Data Quality Control information will be provided in text files and as FITS header keywords. We will also provide quality control information detailing weather conditions e.g. seeing, sky background, noise properties and information from the reduction pipeline e.g. limiting magnitudes for each tile.
- *Level 2 image package*: The intermediate-level data products will primarily contain the **stacked images**

Table 7: Funded FTE commitments per year by VEILS team members and their tasks.

Name	Institution	Role	FTE/yr
		Data processing and quality control	
CASU	Cambridge	Pipeline processing, Quality Control, ESO Phase 3 delivery	0.5†
S. Andreon	INAF Brera	Realtime Photometric Quality Assessment	0.1
L. da Costa	Brazil	Data Quality Control	0.1
R. McMahon	Cambridge	Adapt VHS DQC to VEILS	0.1
VHS PDRA	Cambridge	Adapt VHS DQC to VEILS	0.1
WFAU	Edinburgh	Data Quality Control & Internal Collaboration Data Releases	0.2
M. Banerji	Cambridge	Survey Manager; Delivery of OPC Reports	0.1
		Total DQ & QC	*1.2*
		Static survey	
M. Banerji	Cambridge	Phase 2; Stacked catalogues; combination with optical surveys	0.3
TBD (PhD student)	Cambridge	Stacked catalogues; combination with optical surveys	1.0
M. Jarvis	Oxford	Sky subtraction; Stacked catalogues	0.1
VIDEO PDRA	Oxford	Stacked catalogues	0.5
R. Bowler	Oxford	Stacked catalogues & Catalogue Verification	0.1
A. Muzzin	York	Stacked catalogues & Catalogue Verification	0.1
M. Stefanon	Leiden	Combination with *Spitzer* mid infra-red	0.1
S. Oliver	Sussex	Combination with *Herschel* far infra-red	0.1
D. Farrah	Virginia Tech	Catalogue verification	0.1
C. Conselice	Nottingham	Catalogue Verification	0.1
		Total Static Survey	*2.6*
		Transient survey	
S. Hoenig	Southampton	Single epoch catalogue, light curves, time lags	0.2
B. Boulderstone	Southampton	Single epoch catalogue, light curves, time lags	0.5
M. Sullivan	Southampton	Supernova light curves	0.2
M. Smith	Southampton	Single epoch quality control, classification, light curves	1.0
M. Childress	Southampton	Realtime image subtraction, supernova search (VISTA + VST)	0.2
TBD (PhD student)	Southampton	Object identification; single epoch realtime photometry	0.5
B. Nichol + PhD student	Portsmouth	DES Transient Identification	0.1
		Total Transient Survey	*2.7*
S. Wilkins	Sussex	Public Engagement Materials	0.1
		Total VEILS	**6.7**

†The CASU contribution is expected to be 2.0 FTE for all the VISTA surveys over the duration of the surveys - i.e. 0.7 FTE per year. However, as most of the pipeline processing tasks are common to all the surveys, this FTE is not equally divided between the surveys.

Table 8: The VEILS consortium team members.

Name	Function	Affiliation	Country
M. Banerji	PI & OB Preparation	Cambridge	UK
S. Hoenig	Co-PI & OB Preparation	Southampton	UK
M. Jarvis	OB Preparation	Oxford	UK
CASU (VDFS)	Pipeline Processing	Cambridge	UK
CASU (VDFS)	Data Quality Control I	Cambridge	UK
CASU + WFAU (VDFS)	ESO Phase 3 Delivery	Cambridge, Edinburgh	UK
E. Gonzalez-Solares	Data Quality Control II	Cambridge	UK
M. Jarvis, R. Bowler	Frame Stack	Oxford	UK
M. Jarvis, R. Bowler	Final Stacked Catalogue Production	Oxford	UK
M. Banerji, A. Muzzin	Final Stacked Catalogue Production	Cambridge	UK
S. Hoenig, M. Sullivan	Single Epoch Catalogue Production	Southampton	UK
S. Hoenig, B. Boulderstone	AGN Light Curves	Southampton	UK
M. Sullivan, M. Smith	SN Light Curves	Southampton	UK
M. Childress	Transient identification	Southampton	UK
M. Banerji, A. Schooneveld	DES-VEILS Catalogue Production	Cambridge	UK
J. Greene, M. Strauss	HSC-VEILS Catalogue Production	Princeton	USA
M. Banerji, A. Muzzin, M. Jarvis	Galaxy Photometric Redshifts	Cambridge, Oxford	UK
M. Salvato	AGN Photometric Redshifts	MPE	DE
C. Lidman	OzDES-VEILS Catalogue Production	AAO	AUS
M. Lacy	Spitzer-VEILS Catalogue Production	NRAO	USA
J. Aird, W. Brandt	X-ray-VEILS Catalogues	Cambridge, Penn State	UK, USA
M. Bremer, K. Romer	XMM-VEILS Synergy	Sussex, Bristol	UK
S. Oliver	Herschel-VEILS Catalogues	Sussex	UK
A. Merloni, R. McMahon	4MOST-VEILS Synergy	MPE, Cambridge	DE,UK
M. Cirasuolo, R. Maiolino	MOONS-VEILS Synergy	ESO, Cambridge	DE,UK
A. Baker, N. Maddox	MeerKAT-VEILS Synergy	Rutgers, ASTRON	USA,NL
M. Jarvis	LSST-VEILS Synergy	Oxford	UK
R. Ivison	ALMA Synergy	ESO	DE
A. Verma	E-ELT Synergy	Oxford	UK

for each tile obtained from the Level 1 data, by aligning and combining all individual epochs. Along with these images, we will provide **exposure time maps** and **statistical confidence maps**.

- *Level 3 science products:* The highest level products will mostly consist of catalogues formed from the level 1 and 2 data by using imaging analysis techniques.

  Level 3a: For the static/stacked images, we will provide **band-merged source catalogues in the** J **and** K_S **bands and aperture-matched photometry** with standard isophotal parameters, model profile fitted parameters, object morphological classifications, etc. We will also provide frame associations yielding a survey field system as the reference.

  Level 3b: For the time domain survey, we will use the individual epochs and provide a **variability catalogue** of SNe and AGN within our fields, including photometric variation characteristics, variability detection confidence, and classification. In addition, we will make the full **light curves** (i.e. seamless, merged, multi-colour, multi-epoch source catalogues) available for transient/variability studies.

- *Multi-wavelength catalogues:* We will provide matched catalogues of VEILS with the other multi-wavelength surveys in these fields with the data release timeline for these products dependent on the data release timelines of the ancillary surveys. The first public data release for DES is expected in 2018 (halfway through

VEILS) and the final DES public data release is expected in 2020 (after the end of VEILS). The first public data release for HSC is scheduled for 2017[1] and the first public data release for *Spitzer* DeepDrill is expected in September 2017 (M. Lacy: private communication). We will provide PSF-matched catalogues and photometry from DES/HSC, VEILS and DeepDrill and where possible include matches to X-ray, far infrared (*Herschel*), radio and spectroscopic datasets, that are already public. Key individuals from each of the relevant surveys are members of our team and are listed in Table 8. VEILS when combined with this full suite of multi-wavelength data, will therefore be of enormous legacy value to the astronomy community.

8 Delivery timeline of data products to the ESO archive

As a timeline, we plan on data reduction and release as follows:

Jun 2017 - Sept 2017	Period 99 data being taken
Oct 2017 - Feb 2018	Period 100 data being taken
Oct 2017 - Mar 2018	Period 99 data processing (Level 1)
Apr 2018 - Sept 2018	Period 100 data processing (Level 1)
	Period 99 data processing (Level 2 & 3) and QC[a]
Jun 2018 - Sept 2018	Period 101 data being taken
Oct 2018	**VEILS DR1 - Year 1 Data (P99) - Level 1, 2 and 3a**
Oct 2018 - Feb 2019	Period 102 data being taken
Oct 2018 - Mar 2019	Period 101 data processing (Level 1)
Oct 2018 - Sept 2019	Period 100 & 101 data processing (Level 2 & 3) and QC
	Period 102 data processing (Level 1)
Oct 2019	**VEILS DR2 - Year 1 & 2 Data (P99-P101) - Level 1, 2 and 3ab**
Jun 2019 - Sept 2019	Period 103 data being taken
Dec 2019 - Mar 2020	Period 103 data processing (Level 1)
Apr 2020 - Jun 2020	Period 102 & 103 data processing (Level 2 & 3) and QC
Oct 2020	**VEILS DR3**

(a) Stacking of ES1 field can begin before other two fields.

Should a sixth semester be available as per Observing Strategy A, the timeline would be adjusted accordingly.

[1] http://www.naoj.org/Projects/HSC/surveyplan.html

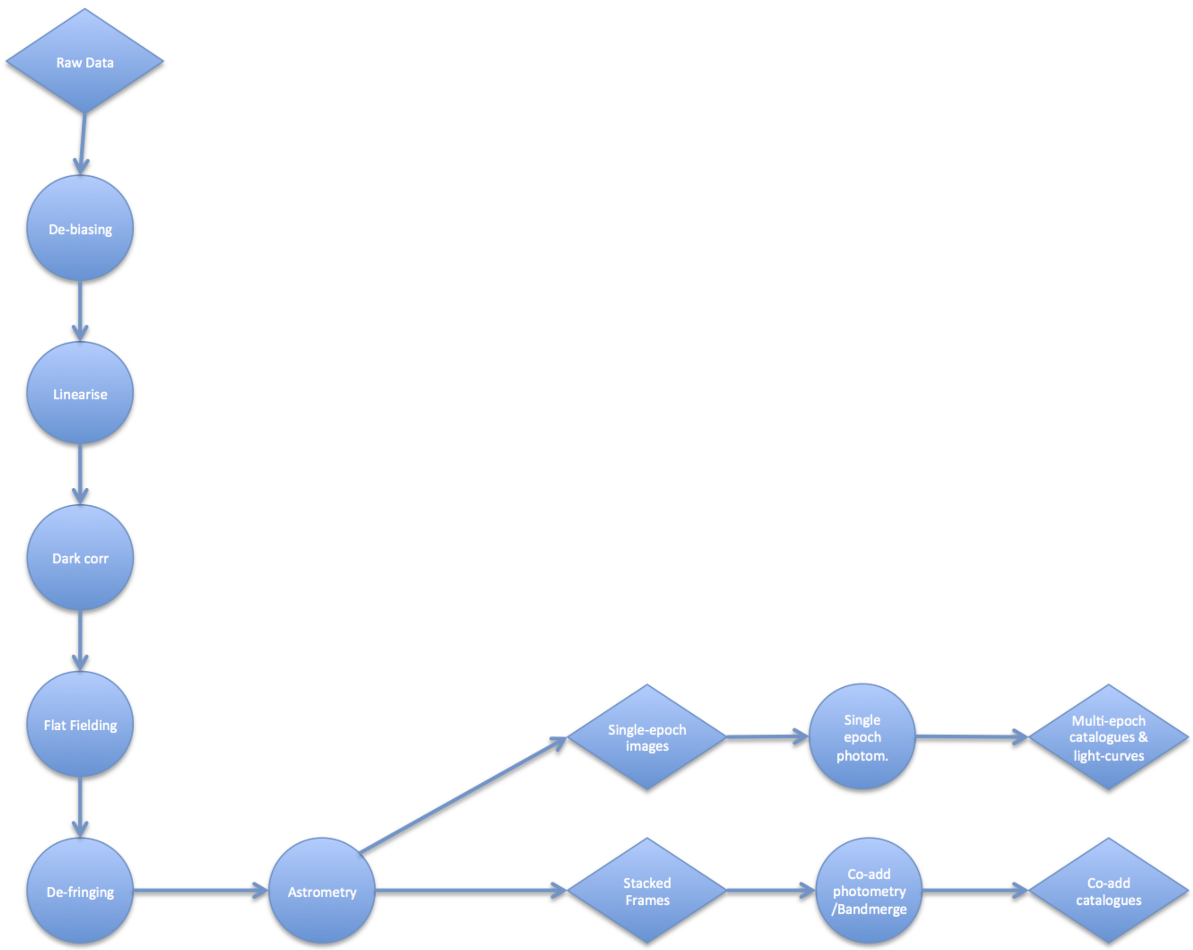

Figure 1: A block diagram synthesizing each step from raw data to the calibrated product is presented.