1 Title: The VVV Extended ESO Public Survey (VVVX)

PI: D. Minniti, Universidad Andres Bello and Millennium Institute of Astrophysics, Chile
CoPI: P. W. Lucas, University of Hertfordshire, United Kingdom

1.1 Abstract

For the past 6 years, the ESO Public Survey VISTA Variables in the Vía Láctea (VVV) has been mapping the IR variability of the Milky Way bulge and southern mid-plane. We propose an extension of this survey to enhance its long lasting legacy. The proposed VVV eXtended Survey (VVVX) will cover the gaps left between the VVV and VHS areas and extend the VVV time-baseline enabling proper motion measurements of $\lesssim 0.3\,\mathrm{mas\,yr^{-1}}$ in the optically obscured regions where *Gaia* is limited by extinction. VVVX will take $\approx$ 2000 hr, and cover 1700 sq degrees in the Southern sky, from $l = -130°$ to $l = +20°$ (7 h<RA<19 h). VVVX will provide a deep JHK_s catalogue of about 2×10^9 point sources, as well as a K_s-band catalogue of $\sim 10^7$ variable sources. Within the existing VVV area we will produce a 5-D map of the surveyed region by combining positions, distances and proper motions of well-understood distance indicators such as red clump stars, RR Lyrae and Cepheid variables in order to unveil the inner structure of the Milky Way. The VVV+VVVX catalogues will complement those from the *Gaia* space mission with very red sources and will feed spectroscopic targets for the forthcoming ESO high-multiplex spectrographs MOONS and 4MOST.

2 Survey Observing Strategy

We will cover an area of 1700 sq. deg. in the Southern sky, from $l = -130°$ to $l = +20°$ as shown in Figure 1. This figure is expanded in Figures 2 and 3, in order to show the tile IDs which are very important for book keeping. The VVVX tiles are oriented along the Galactic coordinates, which has been an advantage for Galactic studies.

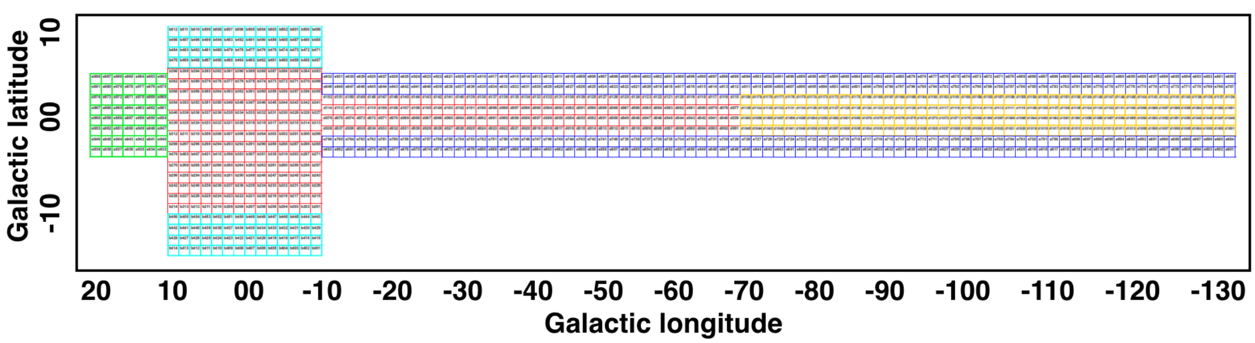

Figure 1: VVVX Survey area. The red area corresponds to the former VVV Survey, which will obtain 3 (and for several tiles 9) additional K_s epochs, to extend the time-base line and allow us to search for high proper-motion objects.

In the bulge this corresponds to 20°x 24°(14 x 22 tiles). These are shown in Figure 2 in red for the former VVV tiles (b201 to b396), and in cyan for the new southern bulge extension from tiles b401 to b456, and for the new northern bulge extension from tiles b457 to b512.

In the northern disk this corresponds to an area of 10°x 9°(7 x 8 tiles). These are shown in green in Figure 2, from tiles e933 to e988.

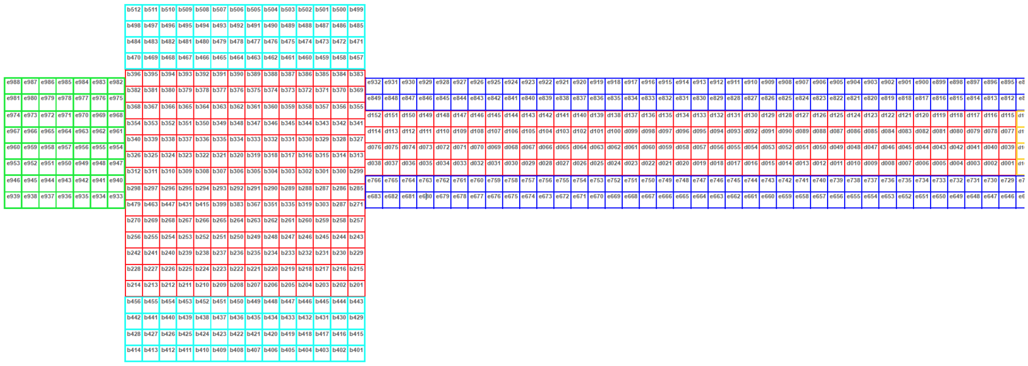

Figure 2: Bulge area and northern section of the VVVX disk area.

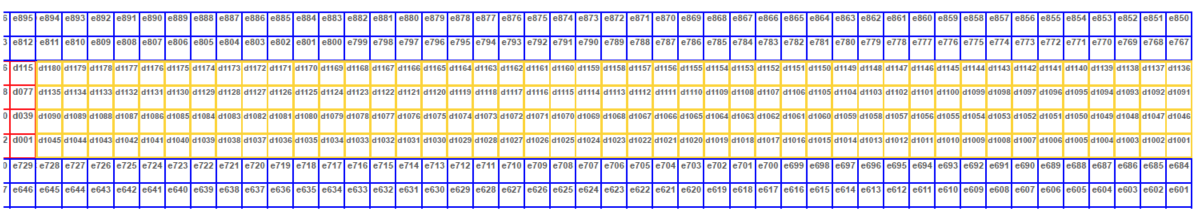

Figure 3: Southern galactic disk area, reaching Galactic longitude 230°, and connecting VVVX with the UKIDSS galactic plane survey.

In the southern disk extension this corresponds to an area of 120°x 9°, consisting of 2 stripes of 83 x 2 tiles each (Figures 2 and 3, in blue, tiles e601 to e766, and tiles e767 to e932) and an extension of the galactic mid-plane region by 65° x 4°, (see Figure 3, in yellow, tiles e1001 to e1180). The original VVV-disk area is also shown in red in Figure 2, consisting of tiles d001 to d152.

Overview of the various VVVX regions, i.e. name, color code, and galactic coordinate range is given in Table 1.

As with the VVV survey, our tiling overlaps by a few arc minutes in Galactic latitude and longitude, in order to ensure spatial continuity, and overall photometric and astrometric consistency. As the edges of the tiles overlap with the neighbouring tiles, this results in a small fraction of duplicate sources, which is advantageous for variable stars, but that must be taken into account when analyzing maps or star counts that are larger than one tile size. The most important lesson learned is that these tile overlap regions allowed to check the photometry and astrometry throughout the survey. Therefore, the VVVX observing strategy also includes similar tile overlaps.

2.1 Scheduling requirements

The VVVX survey area is very large – 1700 sq. degrees, and covers a RA range between 7 h to 19 h. This allows for scheduling VVVX observations in both even and odd ESO scheduling periods. While we do plan to acquire several epochs for any given tile, the experience with the VVV shows that random sampling is sufficient (given a minimum of total observing epochs as requested in the VVVX proposal) and can be easily achieved with concatenations of different tiles with no additional time critical observations. Therefore we do not foresee any special scheduling requirements.

Table 1: Table 1: Specification of the different VVVX survey regions

VVVX region	color code	l_{min}	l_{max}	b_{min}	b_{max}
- VVV- Bulge	red	$350°$	$+10°$	$+10°$	$+5°$
- VVV- Disk	red	$295°$	$350°$	$-2°$	$+2°$
- Bulge-low	cyan	$-10°$	$+10°$	$-15°$	$-10°$
- Bulge-high	cyan	$-10°$	$+10°$	$+5°$	$+10°$
- Disk+20	green	$+10°$	$+20°$	$-4.5°$	$+4.5°$
- Disk-low	blue	$230°$	$350°$	$-4.5°$	$-2°$
- Disk-high	blue	$230°$	$350°$	$+2°$	$+4.5°$
- Disk+230	yellow	$230°$	$295°$	$-2°$	$+2°$

The Period P97 suffered from bad seeing conditions, which did not allow scheduled observations to be carried out. Therefore VVVX was invited to submit 200 hours of early (carry-under) observations, assuming that a slightly higher seeing was permissible. Hence we submited K_s band observations with a 1.2 arcsec seeing constrain, which is somewhat higher than the costumary 1.0 arcsec for the early phases of the variability campaign. The P97 (carry-under) observations represent only to a small fraction of the data, and are considered an exception. For the remainder of the survey we will revert to the 1.0 arcsec and unconstrained seeing conditions of the VVV survey. To take full advantage of the early observation period VVVX was also allowed to include a small amount of good (1.0 arcsec) seeing time, allocated to the Bulge-low and Bulge-high region.

During the first two years (P99 and P101 - 2017) the remaining VVVX area will be observed in the filters JHK_s, as listed in Table 2. This will provide reliable near-simultaneous fluxes and colours for each tile area. The multi-color observations are important because they will provide first information on the underlying stellar population. Therefore these observations should be finished before the variability campaign for a given tile is completed. Therefore we exclude observing semesters P102-104 from the multi-color observations. The early multi-color observations follow the original strategy of the VVV SMP, which also saw the JHK (and YZ) observation as the main part of the first semester (although the observations were not completed until the second year). With the 300 hour limit per semester and the much larger number of tiles it is clearly not possible to follow this 'All multi-color in 2 semester' approach, especially with P99 being a winter semester with statistically worse observing conditions (not only seeing, but also sky transparency). Although we can spread those observations out over 4 semesters (P98 to P101) and taking into account that some have been done already in P97, using all 6 semesters will affect the early science output. For example, the color-magnitude diagram studies for the additional 26 Globular Clusters now included in VVVx. Three K_s-band epochs will be obtained for the VVV bulge tiles, to extend the time coverage in the proper motion studies, with 9 epochs assigned to the region $|b| \leq 2°$. We note that throughout the VVVX Survey the original VVV bulge and disk tiles will be observed in the same tile combinations as used in VVV. However, in order to reduce the overheads (included in the total execution time in Table 2) the tiles of the new areas, i.e. Disk+20, Bulge-low, Bulge-high, Disk+230, Disk-low, Disk-high use larger concatenations in the variability campaign, combining between 8-10 tiles.

During the second year (P101 and P103 - 2018) we will acquire other multiple epoch images in K_s for the whole VVVX area, as listed in Table 2. These extra epochs will improve our ability to detect variable sources. The total number of K_s band epochs for each survey region depends on prominent type of variable stars and the crowdines of the region. In general we will obtain higher number of observations for tiles near the galactic mid-plane ($\sim$ 40) and less for tiles at higher absolute galactic latitude ($\sim$25).

Table 2: Scheduling plan and observing requirements

Period	Target name	RA [h]	DEC [deg]	Filter setup	Tot. exp. time [hrs]	Tot. exec.[1] time [hrs]	Seeing/FLI[2]/ transparency
P97 (carry-under)	VVV-Bulge	17-18.5	-17 to -20	K_s	3	16	1.2/THN[3]
P97 (carry-under)	VVV-Disk	11-17.5	-17 to -42	K_s	2	13	1.2/THN[3]
P97 (carry-under)	Disk+20	18-19	-9 to -22	K_s	8	48	1.2/THN[3]
P97 (carry-under)	Bulge-low	18-19	-25 to -45	JHK_s	15	32	1.0/CLR;1.2/THN[3,4]
P97 (carry-under)	Disk-high	12-17	-25 to -60	K_s	1	7	1.2/THN [3]
P97 (carry-under)	Disk-low	12-18	-15 to -65	K_s	1	6	1.2/THN [3]
P97 (carry-under)	Bulge-low	18-19	-25 to -45	K_s	7	40	1.2/THN[3]
P97 (carry-under)	Bulge-high	16-18	-15 to -35	K_s	8	48	1.2/THN[3]
P99	Bulge-high	16-18	-15 to -35	JHK_s	14	32	1.0/CLR
P99	Disk-high	12-17	-25 to -60	JHK_s	35	80	1.0/CLR
P99	VVV-Bulge	17-18.5	-17 to -20	K_s	5	17	1.0/CLR
P99	Disk-low	12-18	-15 to -40	K_s	16	80	1.0/THN [4]
P99	Bulge-low	18-19	-25 to -45	K_s	1	4	1.2/THN [3]
P100	Disk+20	18-19	-9 to -22	K_s	10	25	1.0/THN [4]
P100	Disk+230	7-12	-15 to -65	JHK_s	46	100	1.0/CLR
P100	Disk+230	7-12	-15 to -65	K_s	29	125	1.0/THN
P100	Disk-low	7-12	-15 to -65	K_s	8	40	1.0/THN
P100	Disk-high	7-12	-25 to -60	K_s	8	40	1.0/THN
P101	Disk-low	12-18	-15 to -40	JHK_s	35	80	1.0/CLR
P101	VVV-Bulge	17-18.5	-17 to -20	K_s	7	35	N.A./THN[5]
P101	VVV-Disk	11-17.5	-17 to -42	K_s	10	52	N.A./THN[5]
P101	Bulge-low	18-19	-25 to -45	K_s	6	32	1.0/THN [4]
P101	Bulge-high	16-18	-15 to -35	K_s	6	32	1.0/THN [4]
P101	Disk+20	18-19	-9 to -22	JHK_s	15	35	1.0/CLR
P101	Disk-high	12-17	-25 to -65	K_s	8	40	1.0/THN [4]
P102	Disk+230	7-12	-15 to -65	K_s	55	235	N.A./THN[5]
P102	Disk-low	7-12	-15 to -65	K_s	8	40	N.A./THN[5]
P102	Disk-high	7-12	-15 to -60	K_s	8	40	N.A./THN[5]
P103	VVV-Bulge	17-18.5	-17 to -20	K_s	7	35	N.A./THN[4]
P103	VVV-Disk	11-17.5	-17 to -42	K_s	10	52	N.A./THN[4]
P103	Disk+20	18-19	-9 to -22	K_s	5	30	N.A./THN[4]
P103	Bulge-low	18-19	-25 to -45	K_s	6	32	N.A./THN[4]
P103	Bulge-high	16-18	-15 to -35	K_s	6	32	N.A./THN[4]
P103	Disk-low	12-18	-15 to -40	K_s	12	60	N.A./THN[4]
P103	Disk-high	12-17	-25 to -65	K_s	12	60	N.A./THN[4]

[1] The total execution time of the observations, including overheads, have been calculated using P2PP v3.4.2.
[2] The JHK_s observations are not affected by the moon, we therefore set no constrains on the lunar phase.

Table 2: continue.

Period	Target name	RA [h]	DEC [deg]	Filter setup	Tot. exp. time [hrs]	Tot. exec.[1] time [hrs]	Seeing/FLI[2]/ transparency
P104	Disk-low	7-12	-15 to -65	K_s	20	100	1.0/THN
P104	Disk-high	7-12	-25 to -60	K_s	20	100	1.0/THN
P104	Disk+230	7-12	-15 to -65	K_s	26	110	1.0/THN

[3] The variability observations of the carry-under observations were- exceptionally- carried out with a slightly higher seeing, i.e. 1.2 arcsec.
[4] The observations include one K_s band observation with a multi-color OB (JHK_s. The K_s observations within the variability campaign (first half) can be carried out under 1.0 arcsec seeing, whereas the later observation have no seeing constraints.
[5] As for the VVV Survey the later epochs for the survey area can be carried out under unconstrained seeing conditions.

2.2 Observing requirements

The total estimated observing time per Period is shown in Table 2 which also shows the requirements on Moon, seeing and transparency conditions. As in the VVV survey we request the early epochs of the variability campaign in the new survey area to be carried out under 1.0 arcsec seeing, whereas the later observing periods can be carried under unconstrained seeing conditions. According the P2PP v3.4.2 this corresponds to a maximum seeing limit of 2.0 arcsec. All observations can be carried out in bright time.

The general limit of 1h:05min for individual containers is obeyed for the variability campaign. The JHK_s observations take 1h:05m:24s for each concatenation, exceeding the above limit. We will apply for corresponding waivers in due time for each Phase 2 submission. The filter order in the multi-color OBs follows the one from the VVV survey- HK_sJ, with the J-band filter at the end of the sequence, to reduce the effects of saturation, which will be more severe in the J-band. We note that due to the 1h:05min limit and the need of combining at least 3 tiles in one concatenation (to improve sky subtraction) the deep multi-color observations are split into HK_sJ and additional J-band observations. The original VVV-Bulge and VVV-Disk regions are not included in the multi-color observations, as those observations were part of VVV survey. No time is required for standard stars, our photometry will be well calibrated using the VVV data.

3 Survey data calibration needs

The VISTA standard calibration plan covers the requirement of the VVVX survey. Data flow and pipelines initiate at the summit for quality control. Instrumental health monitoring, calibration information and library calibration frames are obtained at ESO in Garching. Science data reduction is done at CASU in Cambridge. We do not need any special calibration. The data will be calibrated following the successful calibration strategy of the VVV survey, as described below.

3.1 Detector properties

In order to remove the instrumental signatures the data reduction includes reset, dark, linearity and flat field corrections, sky background subtraction, destripe and jitter stacking (see Section 4). The CASU standard pipeline worked very well with the calibration plan for the VVV survey. The achieved image quality (including seeing) is better than $\sim 0.6''$ on axis with a distortion of up to about 10% across the wide field of view.

3.2 Photometric properties

3.2.1 External photometric calibration

For external photometric calibration, the VVVX Survey does not need to be supported by standard star field observations outside the survey. The photometric calibration and quality control is done using 2MASS stars in the frames themselves, applying color equations to convert 2MASS photometry to the VISTA photometric system, as described in detail in the CASU wabpage[1].

There are hundreds of unsaturated 2MASS stars in JHK_s with photometric errors < 0.1 mag and quality flags of AAA in every VIRCAM detector. A large fraction of these can be sufficiently isolated even in the crowded fields. The colour dependence of the 2MASS to VISTA are derived comparing off-plane VISTA fields, including extinction terms to correct for the effect of interstellar reddening on the colour transformations. This procedure, using the Schlegel and our own extinction maps to estimate the interstellar extinction, has been found to be successful for VISTA in the J, H and K_s filters. Furthermore, the CASU pipeline has undergone several improvements, and is currently at v1.4. These include minor improvements that have been made recently to the extinction terms in the calibration. As more data has been observed, the latest catalogues incorporate the latest version of these equations.

Only one filter (K_s) per single night will be used during the variability campaigns, following the same observing strategy as for the VVV survey. In this case, the calibration scheme for a single star in every particular filter is:

$$m_{cal} = m_{inst} + ZP \times k \times (X - 1) = m_{std} + clr_{std}$$

where m_{cal} is the calibrated magnitude, m_{inst} is the measured instrumental magnitude, ZP is zero point, k is the extinction coefficient, and X is the airmass of the object. From the right side of this equation m_{std} and clr_{std} are the corresponding standard magnitude and color. This assumes that the second-order extinction term and color dependency of X are both negligible. An overall zeropoint for a given frame will be obtained by averaging the zeropoints for every standard star.

3.2.2 Internal photometric accuracy

VISTA data have been used to derive some photometric properties of such as the average zero-points and their variation over the years, the colour equations for each filter with respect to 2MASS and the illumination corrections in all filters. For instance, Figure 5 shows the variation of the zero point over years 2012-2013.

The internal gain-correction in all detectors applied by the flat field should place them on a common zeropoint system. After deriving this ZP in each tile, a double check using the overlap regions will be made to estimate the internal photometric accuracy. The pawprint overlap is large in the X-direction, so internal calibration within 2 groups of 3 points in each tile is very good. The median offset of stellar-like objects will be computed for each overlap region and if there is some visible trend all measurements will be corrected to bring the data to the proper system. Because we can compare the measurements only at the edges of each detector (in the Y direction), this probably will overestimate the internal errors of the final photometry. This cross-calibration using overlaps between tiles will be used to improve our photometric solution and bring all survey data onto a common survey-wide flux scale, as done for the VVV survey.

3.3 Astrometry

Initial nightly astrometric calibration will be achieved using the numerous unsaturated 2MASS point sources available in each field. For the final proper motion and parallax catalogue we will use GAIA to calibrate absolute

[1] http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/photometric-properties

positions and the relative to absolute proper motion and parallax corrections. The WCS distortion model used for VISTA is based on the ZPN projection.

Astrometric calibration incorporates a cubic radial distortion term, but higher order terms can be used if needed, i.e. where the relation between r_{true}, the true on-sky angular distance from the optical axis, and r, the distance measured in a VISTA image, takes the form:

$$r_{true} = k1 \times r + k3 \times r^3 + k5 \times r^5,$$

where the plate scale at the center of the field $k1$ is 0.3413 arcsec/pixel (i.e., 17.065 arcsec/mm). $k3$ and $k5$ are distortion coeficients relative to the angular distance on the focal plane. In angular units of radians the distortion coefficients are $k3/k1 = 44$ and $k5/k1 = 10300$. For VISTA the wavelength dependence and higher order terms are negligible.

After distortion correction the residuals from each individual detector linear fit is used to monitor the quality of the 2MASS-based astrometric solution. The median VISTA WCS rms is ~ 80 mas and is dominated by the astrometric errors in the 2MASS point source catalogue. In the VVV Survey data the typical values for the astrometric accuracy varies from ~ 25 mas at $K_s = 15.0$ mag to ~ 175 mas for faints sources at $K_s = 18.0$ mag.

4 Data reduction process

We will use the VISTA Data Flow System (VDFS; Emerson et al. 2004, Proc SPIE, 5493, 401; Irwin et al 2004, Proc SPIE, 5493, 411; Hambly et al 2004, Proc SPIE, 5493, 423). It will meet all basic data processing and management requirements of our survey once extraction of variables from difference images has been implemented:

(i) removing instrumental signature, merging pawprints into tiles and calibrating photometrically and astrometrically,

(ii) extracting source catalogs on a pawprint and tile bases,

(iii) constructing survey level products - stacked pixel mosaics, difference images and merged catalogs,

(iv) providing the team with both data access and methods for querying and analyzing the data,

(v) producing VO compliant data products for delivery to the ESO archive.

Next, we discuss the individual data processing/reduction steps, to the extent to which the properties of VISTA are currently known.

4.1 Removing the instrument signature, quality control and calibration (Pipeline)

The Cambridge Astronomy Survey Unit (CASU) component of the VDFS will be responsible for the basic pipeline processing and first pass calibration, all done on daily basis. The VISTA pipeline is a modular design allowing straightforward addition or removal of processing stages and has been tested on various datasets. The basic correction includes:

(i) dark/bias will be taken daily for all exposure times and readout modes.

(ii) persistence is a detector memory preserving the knowledge that a bright star was present on a certain array location over a few subsequent images. Unfortunately, bright stars are common in our fields. Fortunately, it is possible to predict where persistence may occur from previous images, and any remnant persistence after jitters mimics an extended source while our project is aimed at point sources. Persistence can still affect our photometric accuracy, therefore we will vary the order in which tiles are observed during the variability campaign, where possible. The persistence in VISTA data can be handled using the VDFS method to remove persistence, being sufficiently reproducible (stable), and possible persistence events can also be flagged.

(iii) flat fielding: At present the reduction strategy generates a set of master flats on a monthly basis. They are based on twilight flats, which are checked by hand prior to their incorporation into the reduction pipeline. The result is an up-to-date set of calibration data, ensuring that a sufficient number of raw flat frames is available, to produce a high quality master flat for each of the filters.

(iv) sky subtraction: perhaps this is the most important of the basic corrections steps because of the large (and variable on time scale of minutes) sky background, in comparison with the targets. We will use the data itself to create a sky frame and then we will subtract it from the individual frames after rescaling to the sky level of the frame. The VISTA experience shows that the residual gradients are below 1%. Some of our fields are very crowded and to improve the sky subtraction will use priorities and concatenation to try to ensure that each night also contains some uncrowded fields for creating skies.

(v) final tile production: the pipeline produces instrument corrected astrometrically and photometrically calibrated pawprint and tiles (with calibration information included in the image headers), extracts object catalogues from these, and updates a database which facilitates monitoring of selected quality control parameters (i.e. seeing, ellipticity of stellar images, sky brightness and noise, zero point and extinction trends. The VVV experience shows that the external astrometric accuracy is better than 100 mas, and the internal one is better than 50 mas. The typical photometric accuracy is at the 1% level.

The pipeline products are: corrected astrometrically and photometrically calibrated tiles in each filter used, confidence maps and homogeneous object catalogues (merged for all filters if observed in same OB (each covering just one tile area). The pipeline records the processing history and calibration information of each file in the FITS header, including calibration files and quality control parameters.

4.2 Combination/image subtraction (archive)

The second order data processing requires higher access to larger sets of data to produce survey products. This process is done at the Wide Field Astronomy Unit (WFAU) VISTA Science Archive (VSA) in Edinburgh, following the data proccessing as depicted in Figure 4. The Science Archive contains only calibrated data and catalogs, it does not contain any raw data. The Science Archive is responsible for:

- Image stacking to produce stacked and differenced tiles, and source merging: obviously, in the case of the VVVX the same field is observed more then once. This implies a capability to merge both tiles and catalogs derived from different tiles in the same area. Naturally, these procedures can not be implemented by the pipeline which at any time operates only on science data from a given night. Therefore both coadding and differencing combination is performed at the Science Archive where the combining tools have access to all multi-epoch data. The VDFS stacking and merging are described in Irwin et al. (2007) and Hambly et al. (2007). This post-processing allows to facilitate complex requirements such as measuring upper limits for an object detected in some bands for all other bands in which this object was not detected or selection of objects from multi-color criteria, in cases where the imaging in the different filters was carried out at different times.

- Quality Control (QC): assessment of the data quality and filtering of the data that do not meet the established criteria for photometric and astrometric accuracy. The multiple epochs of our VVV Survey naturally allows quality control by internal comparison. External comparisons (e.g. 2MASS) will also be used for quality control and calibration in the appropriate filters.

- Identification of Variables: Very importantly, the Archive can implement an image subtraction analysis algorithm devised and tested by the VVV team, that will allow us to create the catalog of variable sources and to derive their light curves. Direct point source photometry will also be performed for data in all filters. In addition, the image subtraction part of the analysis (Alard 2000, A&ASuppl., 144, 363; Alard & Lupton 1998, ApJ, 503, 325) will also be implemented, and will only be used to perform a more detailed analysis of a few specific fields (e.g., star clusters, the galactic centre, etc).

The variability detection will be carried out only after a sufficient VVVX data are accumulated (in year 3). This method provides excellent results for crowded fields in which the traditional aperture or PSF-fitting photometry fails because of the contamination from the nearby sources.

Our project taps into both the VDFS team experience handling the VISTA data, and the experience of the VVV team members who are leading participants in the routine data processing and delivery to ESO.

Our experts on the variability detection are Dekany (Heidelberg), Alonso-Garcia (UANTOF), Minniti (UNAB), Contreras and Catelan (PUC), Borissova (UV), and Rejkuba (ESO). They will interact with the Archive unit for the implementation of the procedures.

4.3 Additional data products

4.3.1 Variability analysis

The members of the team in Chile will carry out the final analysis: variability studies, including light curves fitting, period determination, source identification/classification. etc. The steps here are:

(i) Variable selection according to robust criteria.

(ii) Preliminary variable classification (using peak to peak amplitudes, color-magnitude diagrams, color-color diagrams, etc.).

(iii) Period determination for periodic objects (roughly half of the variable objects are expected to be periodic according the experience of the microlensing databases, the rest are not periodic or transients or fluctuations in the data).

(iv) Light curve fitting where appropriate.

4.3.2 Other

The proper motion and parallax fitting will be produced by a collaboration between staff at Hertfordshire (P. Lucas, L. Smith) and Valparaiso (Kurtev, Borrisova, Gromadski). The datasets are UKIDSS GPS (near IR), GAIA, OGLE, VPHAS+ (optical), WISE, GLIMPSE and GLIMPSE-360 (mid-IR). In addition, members of the team in Europe (Gonzalez, Cross) will take the lead in cross checking and combining the data with other large datasets. This will lead to:

- improved extinction maps for the survey region.

- determination of most likely spectral type and luminosity class for all stars detected in multiple wavebands.
- identification and classification of Young Stellar Objects.
- identification of star clusters.
- proper motion measurements, identification of high-PM objects.
- input catalogues and tools for forthcoming IR spectroscopic surveys (MOONS).

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

5.1 VDFS manpower and hardware

As already described we will use the VISTA Data Flow System (VDFS) for all aspects of data management, including: pipeline processing and management; delivery of agreed data products to the ESO Science Archive by internet transfer.

The VDFS is a collaboration between the UK Wide Field Astronomy Units at Edinburgh (WFAU) and Cambridge (CASU) coordinated by the VISTA PI (QMUL) and funded for VISTA by STFC. The Cambridge Astronomy Survey Unit (CASU-VDFS) team consists of Gonzalez-Fernandez, Gonzalez-Solares, Irwin, Lewis, Walton, Yoldas. The WFAU (VDFS) team consists of Blake, Collins, Cross, Davenhall, Holliman, Morris, Read, Sutorius, Voutsinas. The VDFS is a working system that is already being successfully employed for the VISTA infrared surveys, and which is sufficiently flexible as to be applicable to any imaging survey project requiring an end-to-end (instrument to end-user) data management system. We emphasize the track record over the last two decades of both the Cambridge and Edinburgh survey units in processing and delivering large-scale imaging datasets to the community as demonstrated by previous UKIDSS and VISTA data releases (e.g., Dye et al 2006, MNRAS 372, 1227; UKIDSS DR1 Warren et al 2007 MNRAS 375, 213; VVV DR1, Saito et al. 2012, A&A 537, 107)

The VDFS pipeline and archive teams each have, by design, appropriate hardware to handle VISTA data and products, as verified by success in handling the VVV data. The VDFS Science Archive uses a commercial relational database management system for creating imaging and catalog products on-demand via web interface applications that provide access to the database through Structured Query Language (SQL) queries. The two VDFS Units (CASU & WFAU) are funded by long term 'rolling' grants and were built up specially to handle VISTA data, using WFCAM data as a real test bed.

5.2 Other manpower and hardware

In addition to the UK VDFS, the VVV survey team involves astronomers from institutes in Chile, UK, Brazil, Argentina, Germany, Italy, France. Our team includes European Southern Observatory staff experienced in all aspects of IR imaging and instrumentation. We have a proven track record of data reduction, pipeline, photometry, astrometry, database, light curves, and simulations. We are requesting Chilean Fondecyt funding for hardware (computers, database, infrastructure), and for manpower (students). Another independent national funding project that has always supported the VVV (BASAL) has just been renewed for 3 more years. Finally, we have the Millennium Institute of Astrophysics (MAS) that can partially support the VVVX, and we are hiring a postdoc who will be substantially dedicated to the VVVX Survey.

We will count on the following people: 7 postdocs (5 of which are based in Chile): 2 at UNAB; 2 at UV and 2 at PUC; 1 at UdeC; 2 at Hertfordshire and 4 PhD students: 2 at PUC; 1 at UV; 1 at UNAB. This makes already 13 FTE per year, plus the time dedicated by the professors and senior staff, for the duration of the VVVX (3 years). It is true that most of the professors will dedicate to the VVV only a fraction of their time, but they are key persons in their institutions, and will be crucial to apply for funding and hire more manpower when needed. Therefore, we have enough FTE and capable people in charge of the data reduction, pipeline, photometry, astrometry, database, light curves, and simulations.

5.3 Detailed responsibilities of the team

We have created a web page that will be regularly updated with information on the VVVX survey progress. We have included a commitment statement from each Team member. We report here just a summary of the main responsibilities.

Minniti and Lucas will lead the science team, Irwin will lead the CASU team and Cross will lead the VSA team, and they will manage and be involved in all aspects of the project. They will hold regular videocons and meetings, including other key team members as appropriate, to inform and review VVVX progress and to negotiate the assignment of tasks to team members as necessary. They will manage the survey in response to actual performance, rate of progress and events, and be responsible for the necessary reports and data releases.

As described in the next section there will a 5-10 member Quality Control Team from which, at any one time, there will always be (at least) one 'duty' member monitoring the VDFS products and processing. We are assuming steady state, naturally there may be stages in the survey there will be an even more intense level of effort required from the team members, who are able and willing.

Ivanov, Zoccali, Catelan and Rejkuba will help deciding the data taking strategy and scientific priorities. Catelan will lead the variable star templates and automated classification efforts.

Hempel, Saito, Palma and Rejkuba will lead the Phase 2 activities, including OBs preparations. Lucas, Minniti, Irwin and Cross will lead the Phase 3 efforts, aided by Hempel, Saito, Dekany, Palma, and Alonso-Garcia. All members of the collaboration will be involved in the photometry (including PSF/DIA) led by Alonso-Garcia, Mauro, and Contreras. Hempel and Dekany will lead the Monte-Carlo simulations to compute photometric completeness and sampling/variability efficiencies. The astrometry will be carried out by Contreras, Lucas, Gromadzki, Beamin, Gonzalez. Catelan and Dekany will decide on variability and phasing criteria. Dekany, Bica and Chene will take charge of creating the variability catalogue.

In addition, all team members will participate in the annual Science Team workshops, in the outreach efforts, and collaborate in the preparation of the major data release papers (as done with the VVV), and in the scientific exploitation of the database.

A complete list of team members, their affiliation and assigned duties (where applicable) is given at the end of the document. Please note that all team members have their own specific VVV+VVVX science projects, which are not listed here. However, the analysis of the data, and in particular follow-up observations (photometric, spectroscopis), provide a quality asesseement that is unreachable for the routine QC, and that will characteris the survey data in much deeper detail.

6 Data quality assessment process

The team realizes the importance of the timely quality control process, especially considering how important any long-term trends will be for our variability analysis. With the VVV survey experience we have a well developed QC routine in place for VVVX. The QC duty involves:

- check master frames used.
- check random reduced tiles logging in the VDFS VISTA Science Archive. The pipeline is well behaved and the frequency with which problems occur is low. We select a pipeline reduced tile as a basic QC element for our Survey because the raw data contain strong instrument signatures (i.e. gradients and patterns before the flat fielding) that might mask real artifacts. Our examination aims to discover unusable data due to

for example to artifacts and strange patterns produced by the detector, moon ghosts, trailed frames, etc. However, most problems are detected by the automated tools. The raw data will be inspected only to trace problems if unexpected telescope or camera problems arise.

- check the behaviour of the pipeline and archived QC parameters by generating and inspecting QC plots.

We will then produce a number of critical QC parameters produced by the pipeline:

- Quality of the pipeline reduction to detect for example frames where the sky subtraction is not satisfactory, frames suffering from extreme bias offsets, etc.
- The ellipticity for all stellar objects will be calculated as a quality control parameter in the pipeline. The measured values are around or less than 0.1. It is possible to have elongated images, especially at high airmass, and these should be identified and removed.
- The limiting magnitude or the depth of the tiles. The expected single epoch limiting magnitude and in the K_s band are the same for Bulge and Disk tiles. We will not apply any specific depth cuts to the observations, since all frames can contribute the depth in the stack images. But, we usually eliminate a few frames that are taken in conditions of very bright sky (usually a few percent) in order to keep the quality.
- Photometric zero point. Since we are asking for clear and thin (not necessarily photometric) conditions we use the computed zero point for each frame, relative to the mean value for the corresponding filter as an indicator of how much cloud extinction is there. Since the goal is to search for variable stars method the variation of the photometric zero point should lie within 0.1 mag of the mean value.

The QC parameters described above will be regularly reported to the rest of the QC team and as well as ESO.

7 External Data products and Phase 3 compliance

The standardised VO compliant data products produced by the VDFS science archive for VVVX in Edinburgh will be delivered to ESO by internet transfer, with a copy remaining at the Science Archive in Edinburgh. These are the calibrated tiles and with their associated source catalogues and the higher level merged science products described in Section 4.

8 Delivery timeline of data products to the ESO archive

The VVVX survey will operate for three years and will finally cover 1700 sq. deg. of Milky Way giving new and interesting data to the community through the Phase 3 release to ESO. All the final objectives of the project will be obtained by merging or differencing different modular blocks of observations achieved during each years of the survey. For this reason the schedule of the data products release is mainly defined by the survey observing strategy.

The VDFS team will release the data to the PIs within two months of the raw data arriving in UK. After further work by the survey team, including QC checking, the annual public releases of VVVX data products to the ESO Science Archive are expected to occur **six months to a year** after the end of the VVV observing season.

A realistic schedule based on our VVV experience will be as follows: The VDFS team will release the data to the PIs within two months of the raw data arriving in UK. After further work by the survey team, including QC checking, the annual public releases of VVVX data products to the ESO Science Archive are expected to occur **six months to a year** after the end of the VVV observing season.

In detail data products are expected to appear in the ESO science archive with a yearly release schedule as follows:

- Year 1 + 6 months - Release of completed tiles observed in JHK_s bands at first survey epoch (Year 1 of the survey) together with associated merged and tile-based catalogues.
- Year 2 + 6 months - Release of completed tiles of the K_s band epochs taken during Year 1 and Year 2 of the survey, together with associated catalogues as well as any JHK_s band multi-colour tiles completed during Year 2.
- Year 3 + 6 months - Release of the data products of the year 3 variability campaign. This will comprise K_s band tiles, a merged catalogue with fluxes from all epochs and a list of variable sources. Then the delivery of the final survey data products that will have a proper motion catalogue, stacked K_s tiles, as well as the final variability catalogues.

The completeness of the coverage in the whole planned observing area is key for meeting the final aim of the variability survey, and after all observations are complete we expect to a final variability catalogue with phasing, identification and classification of periodic variables and transients (novae, microlensing).

Data for the final release of VVV source lists and tile images are being uploaded at present, now that CASU have fixed a subtle bug in all the VISTA data they have processed from Feb 2015 to Feb 2016 (reported to the ASG in Sep 2016). We have begun to prepare for release of the light curves, variable star catalogues, and band-merged photometry for this final release, in parallel with the more advanced products: PSF photometry and proper motion catalogues. We anticipate delivery of these band- merged products in H2 2017. Also, we expect that VVV time series data will be included in future VVVX products, for stars common to both surveys.

We aim at a consistent data set over the whole area that will be done initially with aperture photometry and later with PSF-photometry. We will also obtain PSF photometry for the whole VVVX area, which is important for some projects. This must be done on a tile basis averaging the results for component pawprints after the imaging is complete, as we have done for the VVV. In the VVV fields near the galactic plane the PSF photometry provides the most complete source catalogs, and most VVVX fields are farther away from the plane where the CASU photometry should be quite accurate. Taking into account the variability of the PSF across a tile - previous experience with VVV and recommendations from CASU make it clear that tiles are not suitable for PSF-photometry, hence that will be based on paw-prints and the source catalogs matched afterwards.

For example, the proper motions of stars in the VVVX area will be delivered in the high level catalog products, as an additional, independent catalogue. These proper motions need to be measured after we build a time baseline. This will be done when the observations are complete and the data fully analysed. Optimistically, we aim to do the Phase 3 including proper motion catalog, stacked K_s tiles, variability catalog with identification of variables and phasing within three years of start of operations. Realistically, we expect that some of these may take a bit longer, based on the VVV experience with the large amount of data.

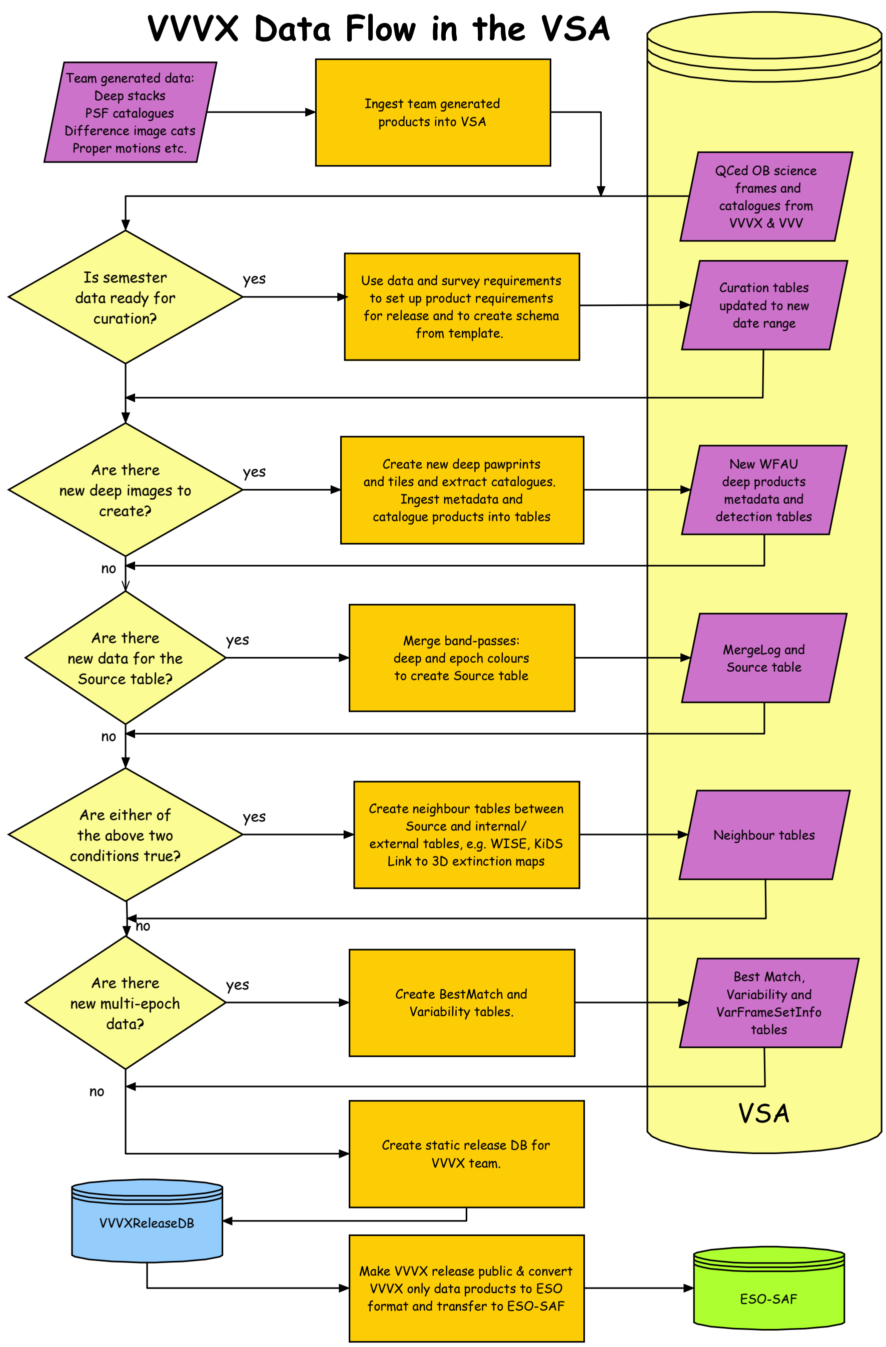

Figure 4: Pipeline flow chart for the VVVX survey at VSA.

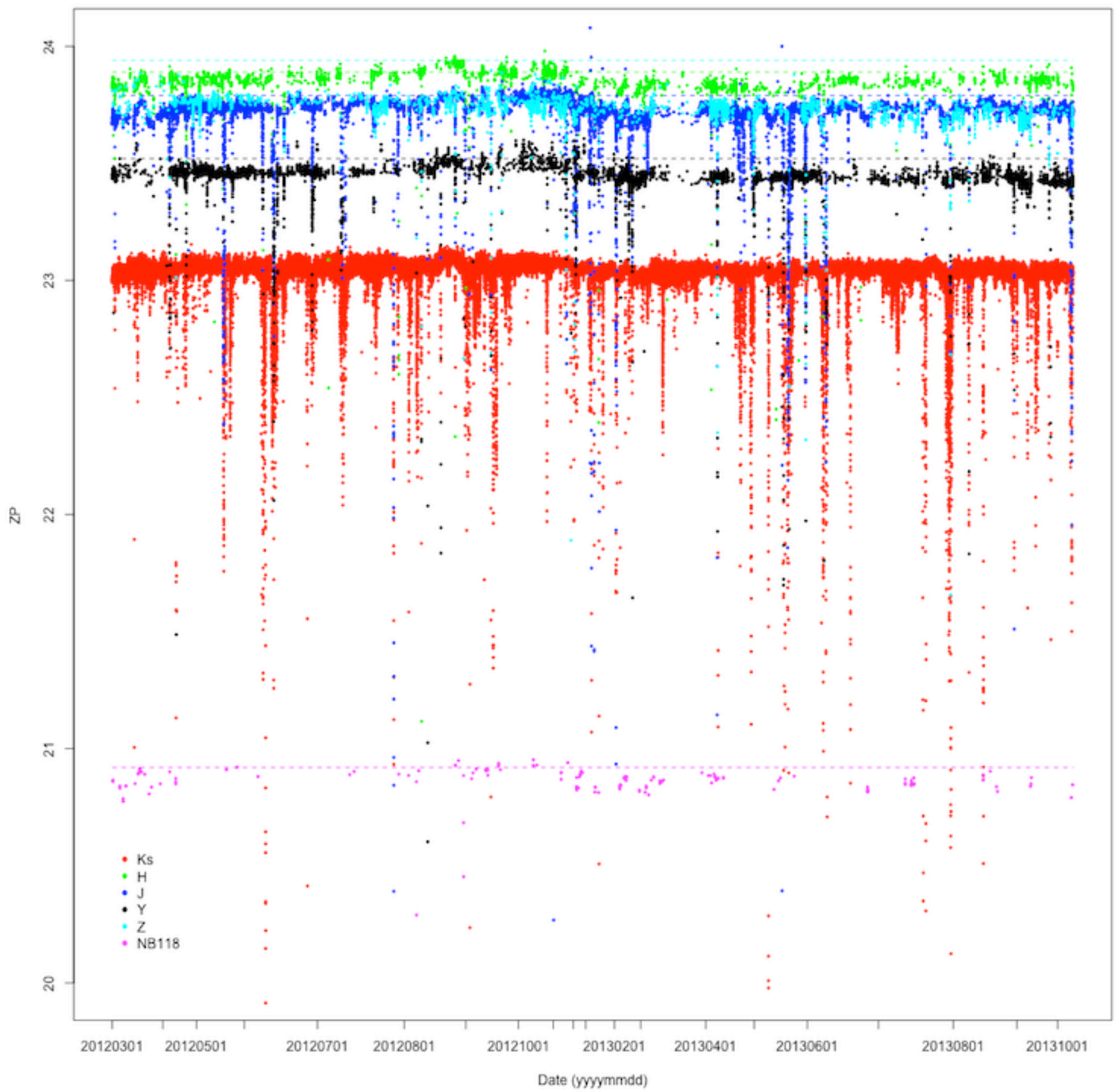

Figure 5: Variation of the zero point through years 2012-2013, after the VISTA mirror recoating in September 2009 and April 2011 (Figure from CASU[3]).

[3]http://casu.ast.cam.ac.uk/surveys-projects/vista/technical/photometric-properties

Table 3: Allocation of resources within the team.

Name	Function	Affiliation	Country
D. Minniti	**PI, survey management**	**Universidad Andres Bello**	**Chile**
P. Lucas	**Co-PI, survey management**	**University of Hertfordshire**	**UK**
A. Adamson		Gemini South, La Serena	Chile
M. V. Alonso		Instituto de Astronoma Teorica y Experimental	Argentina
S. Alonso		Consejo Nacional de Investigaciones Científicas y Técnicas	Argentina
J. Alonso-Garcia	PSF, and DIA photometry	Univerdad de Antofagasta	Chile
R. Angeloni	template project	Gemini South, La Serena	Chile
R. Barba	P2PP	Universidad de La Serena	Chile
B. Barbuy		Universidad de Sao Paulo	Brazil
L. Barvalle		Instituto de Astronoma Teorica y Experimental	Argentina
J.C. Beamin		Universidad Valparaiso	Chile
L.R. Bedin		Universita degli studi di Padova	Italy
E. Bica		Universidade Federal do Rio Grande do Sul	Brasil
Ch.J. Bonatto		Instituto de Fisica, Universidade Federal do Rio Grande do Sul	Brazil
J. Borissova		Universidad de Valparaiso	Chile
C. Canavaro-Navarete (s)	variability	Instituto de Astrofisica, PUC, Santiago	Chile
J.L.N. Castellon		Departamento de Física y Astronomá, Universidad de La Serena	Chile
M. Catelan	data taking strategy and scientific priorities	Instituto de Astrofisica, PUC, Santiago	Chile
A.-N. Chené	variability catlogs	Gemini North	USA
R. Chen		Max-Planck Institute for Radioastronomie, Bonn	Germany
S. Clark		University College London	UK
J.J. Clariá		Observatorio Astronómico de Córdoba	Argentina
M. Cirasuolo		ESO, Garching	Germany
R. Cohen	PSF, and DIA photometry	StscI	USA
G. Coldwell		Consejo Nacional de Investigaciones Cientficas y Técnicas	Argentina
R. Contreras		Instituto de Astrofisica, PUC, Santiago	Chile
J.M. Corral-Santana		Instituto de Astrofisica, PUC , Santiago	Chile
C. Cortes		Universidad Metropolitana de Ciencias de la Educación, Santiago	Chile
N. Cross	aperture photometry, VSA	Royal Observatory Edinburgh	UK
R. de Grijs		KIAA, Beijing University	China
V. Debattista	modelling	Astronomy Technology Centre, Edinburgh	UK

Table 4: Allocation of resources within the team

Name	Function	Affiliation	Country
I. Dekany	variability, phasing	ARI Heidelberg	Germany
B. Dias		ESO, Santiago	Chile
L. Donoso		Instituto de Astronoma Teorica y Experimental,	Argentina
J. Drew		University of Hertforsdshire, Hatfield	UK
F. Duplanic		Consejo Nacional de Investigaciones Científicas y Técnicas	Argentina
C. Eduardo		SUPA- WFAU, IfA, University of Edinburgh, Royal Observatory	UK
C. Evans		Astronomy Technology Centre, Edinburgh	UK
S. Eyheramendy Duerr	automatic classification	Pontificia Universidad Católica de Chile, Santiago	Chile
V. Firpo		Universidad de La Serena	Chile
D. Froebich		University of Kent	UK
D. Geisler	photometry	Universidad de Concepcion	Chile
O. Gerhard		MPE Garching	Germany
W. Gieren	variability, phasing	Universidad de Concepcion	Chile
O.A. Gonzalez	astrometry, spectroscopic follow-u	Astronomy Technology Centre, Edinburgh	UK
C. Gonzalez-Fernandes		CASU, Cambridge	UK
E. Gonzalez-Solares	data reduction	Cambridge University, CASU	UK
F. Gran (s)		Instituto de Astrofísica, PUC, Santiago	Chile
M. Gromadzki	astrometry	Universidad Valaparaiso	Chile
S. Gurovich		Universidad de Cordoba	Argentina
G. Hajdu (s)	variability	Instituto de Astrofísica, PUC, Santiago	Chile
N. Hambly		Royal Observatory Edinburgh	UK
M. Hempel	P2PP, photometric completeness, sampling efficiency	Instituto de Astrofísica, PUC	Chile
M. Hilker		ESO, Garching	Germany
S. Hodgkin		CASU Cambridge	UK
M. Irwin	CASU pipeline, aperture photometry	IfA, Cambridge	UK
V. Ivanov	data taking strategy and scientific priorities	ESO, Garching	Germany
H. Jones		University Hertfordshire, Hatfield	UK
M. Kuhn		Universidad Valpardiso	Chile
R. Kurtev	astrometry	Universidad de Valparaiso	Chile
N. Kumar		University of Hertfordshire, Hatfield	UK
E. Lima		Departamento de Astronomia IF-UFRGS, Porto Alegre	Brasil

Table 5: Allocation of resources within the team

Name	Function	Affiliation	Country
T. Maccarone		Texas Tech University, Lubbock	USA
D. Majaess		Mount Saint Vincent University	Canada
E. Martin		Centro de Astrobiología, Instituto Nacional de Técnica Aeroespacial	Spain
F. Mauro	PSF, and DIA photometry	Millennium Institute of Astrophysics (MAS), Concepcion	Chile
I. McDonald		University of Manchester	UK
A. Meza (s)		Departamento de Ciencias Físicas, Universidad Andrés Bello	Chile
J. Minniti (s)		Instituto de Astrofísica, PUC, Santiago	Chile
Ch. Moni Bidin	P2PP	Universidad Catolica del Norte, Antofagasta	Chile
V. Motta		Universidad Valparaiso	Chile
M. Moyano D'Angelo'		Universidad Catolica del Norte, Antofagasta	Chile
D. Nataf		ANU, Canberra	Australia
C. Navarro		Universidad de Valparaiso	Chile
T. Naylor		University of Exeter	UK
L. Origlia		INAF-Osservatorio Astronomico Bologna	Italy
T. Palma	P2PP, variability	Universidad Andres Bello, Santiago	Chile
P. Pessev		GTC, Instituto de Astrofisica de Canarias, La Laguna	Spain
K. Pena	photometry	PUC, Universidad Valparaiso	Chile
B.K. Pichara	automatic classification	Departmento de Engineria, PUC, Santiago	Chile
B. Popescu		University of Cincinnati	USA
J. Pullen	outreach	Universidad Andres Bello, Santiago	Chile
S. Ramirez		Instituto de Física y Astronomía, Universidad de Valparaíso	Chile
M. Rejkuba	data taking strategy and scientific priorities, P2PP	ESO, Garching	Germany
A. Rojas		Observatoire de la Cote d'Azur', Nice	France
B. Rojas Ayala		Universidad Andres Bello, Santiago	Chile
A. Roman		Universidad de La Serena	Chile
A.C. Robin		University of Franche-Comté	France
R. Saito	P2PP, variability, LC phasing	Universidade Federal de Santa Catarina	Brazil
A. Schroeder		South African Astronomical Observatory, Cape Town	South Africa

Table 6: Allocation of resources within the team

Name	Function	Affiliation	Country
M. Schultheis		Observatoire de la Côte d'Azur	France
M. Soto		Space Telescope Science Institute, Baltimore	USA
B. Stecklum		Universitätssternwarte Tautenburg, Tautenburg	Germany
D. Steeghs		Warwick University	UK
F. Surot		ESO, Garching	Germany
W. Taylor		Astronomy Technology Centre, Edinburgh	UK
I. Toledo		ALMA, Santiago	Chile
A.A.R. Valcare		Instituto de Astrofísica, PUC, Santiago	Chile
E. Valenti	photometric completeness, sampling efficiency, variability, phasing	ESO Garching	Germany
J. Vargas		Universidad de La Serena	Chile
N. Walton		IfA, Cambridge	UK
C. Wegg		Max-Planck Institute for Extraterrestrial Physics, Garching	Germany
A. Zijlistra		Manchester University	UK
M. Zoccali	data taking strategy and scientific priorities	Instituto de Astrofísica, PUC, Santiago	Chile