1 VANDELS: A deep VIMOS survey of the CANDELS UDS and CDFS fields

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1.1 Abstract

VANDELS is a uniquely *deep* VLT spectroscopic survey of high-redshift galaxies, carefully designed to exploit the multi-wavelength imaging and near-IR grism spectroscopy available in the CANDELS UDS and CDFS fields. Our aim is to move beyond redshift acquisition, obtaining spectra with high enough signal-to-noise to derive metallicities and velocity offsets from absorption and emission lines, allowing a detailed investigation of the physics of galaxies in the early Universe. Using integration times set to obtain a constant S/N ($20 < t_{int} < 80$ hours), we will target: *a)* $2.5 < z < 5.5$ star-forming galaxies with $H_{\rm AB} \leq 24$ ($I_{AB} \leq 25$), *b)* $H_{AB} < 22.5$ passive galaxies at $1.5 < z < 2.5$; *c)* fainter ($H_{AB} \leq 27$) star-forming galaxies at $3.0 < z < 7.0$ and *d)* X-ray/radio selected AGN. Our strategy will deliver ≥ 2500 high signal-to-noise spectra within an area of $\simeq 0.2$ deg^2. Combining the proposed VIMOS spectroscopy with the best optical+nearIR+Spitzer imaging will produce a unique legacy dataset, capable of unveiling the physics underpinning high-redshift galaxy evolution.

2 Survey Observing Strategy

VANDELS will target the UDS and CDFS with four overlapping VIMOS pointings per field, designed to provide full coverage of the WFC3/IR imaging provided by CANDELS (see Fig. 1). We intend to design four VIMOS masks per pointing (i.e. 32 masks in total), observing each mask for 20 hours of on-source integration. The instrument set-up for all observations will be identical: MR grism+GG475 order sorting filter, 1″ slit widths and a minimum slit length of 6″. Using this instrumental set-up, repeated simulations with VMMPS indicates that we can typically allocate up to 180 slits per mask set (i.e. up to 45 slits per VIMOS quadrant). The pointings (Fig. 1) are placed to ensure that each VIMOS quadrant always intersects the CANDELS *HST* imaging which, due to the high surface density of faint $z \geq 3$ galaxies, allows us to maximize the number of slits in the central *HST* area. All slits will be oriented E-W on the sky in order to minimize slit losses during long integrations on fields at the declinations of the UDS and CDFS. To ensure that our slits can be placed with maximum accuracy we will use $R-$band pre-imaging obtained in P94 to properly account for VIMOS focal plane distortions and allocate 1-2 bright reference stars to each VIMOS mask.

To accommodate the range of exposure times needed to meet our science goals we will pursue a nested slit allocation strategy, whereby objects requiring 80 hours of integration are retained on all four masks, those requiring 40 hours are included on two masks and those only requiring 20 hours integration appear on a single mask. The following table illustrates our slit-allocation for a single VIMOS quadrant over a series of four masks. The columns indicate the number of objects that would be observed for 80 (N80), 40 (N40) and 20 hours (N20):

Mask	N80	N40	N20	Total
1	20	20	5	
2	20	20	5	
3	20	20	5	
4	20	20	5	
no. of spectra	20	40	20	80

Using this nested strategy, each quadrant provides 20 objects which receive 80 hours of integration (retained on all 4 masks), 40 objects which receive 40 hours of integration (two sub-samples of 20) and 20 objects which receive 20 hours of integration (four sub-samples of 5).

The eight VIMOS pointings are designed to provide a total of 2560 spectra, comprised of 640 (N80), 1280 (N40) and 640 (N20) targets. Uniquely, 75% of our targets will receive 40+ hours, with 25% receiving 80 hours.

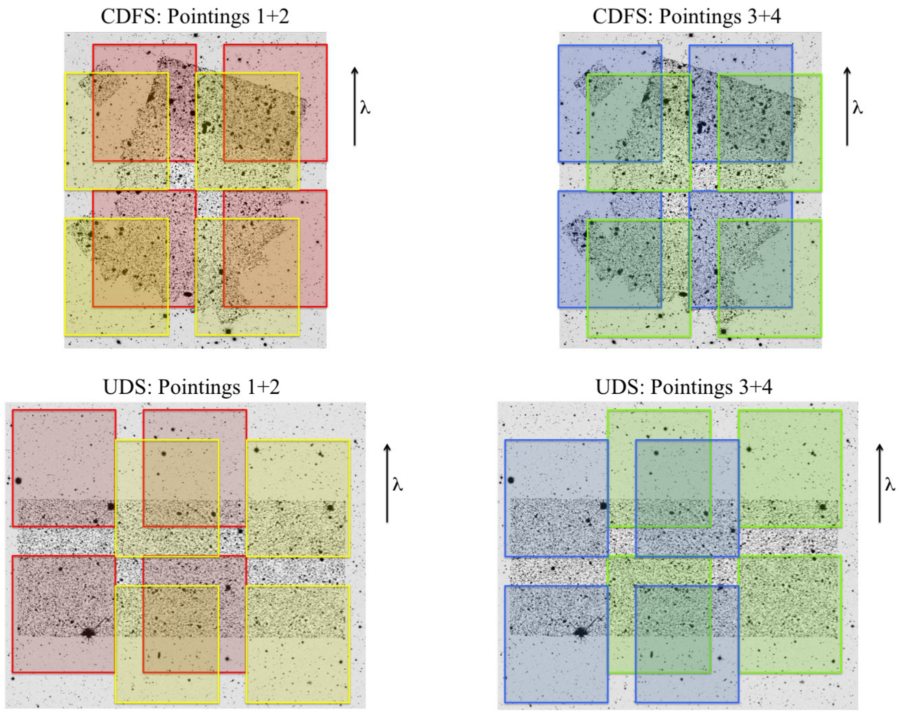

Figure 1: Layout of the proposed VANDELS pointings (4 in UDS and 4 in CDFS). In each figure the VIMOS quadrants of a given pointing are shown as a different colour, overlaid on a greyscale image showing the available *HST* $H-$band imaging (centre) and wider-area, ground-based, $H-$band imaging. The total area covered by the eight VIMOS pointings is $\simeq 0.2$ square degrees. The quality of the multi-wavelength data available over the wider UDS and CDFS fields is now excellent, and more than sufficient to select $H \leq 24$ targets over the full VANDELS footprint. The pointings are placed to ensure that each VIMOS quadrant always intersects the CANDELS *HST* imaging which, due to the high surface density of faint $z \geq 3$ galaxies, allows us to maximize the number of slits in the central *HST* area. The spectroscopic slits will be placed E-W on the sky, as recommended to minimize slit losses during long integrations on fields at these declinations (Sánchez-Janssen et al. 2014).

Demonstrating the impact of 40-80 hour integrations:
The VANDELS observing strategy is designed to provide consistently high signal-to-noise ratio (SNR) continuum detections for the bright star-forming ($H_{AB} \leq 24$) and passive galaxy ($H_{AB} \leq 22.5$) sub-samples. For those objects with $I_{AB} \leq 24.5$, the final 1D spectra should provide a SNR/pix in the range $15-20$, based on total exposure times of 20, 40 or 80 hours. For the faintest objects in these sub-samples ($I_{AB} \simeq 25$), the final spectra will have a SNR/pix of $\simeq 10$ based on 80 hours of integration. For the fainter ($H_{AB} \leq 27$) star-forming galaxies at $z \geq 3$, the VANDELS observing strategy is designed to provide a consistent Lyα emission-line detection limit of $\simeq 2 \times 10^{-18}$erg s^{-1}cm^{-2} (5σ).

In order to justify such long integration times, it is clearly necessary to demonstrate that our observing strategy and data reduction techniques produce final data products with the expected signal-to-noise ratios. The provisional schedule for VANDELS is designed to ensure that two of our eight VANDELS pointings (one in UDS and one in CDFS) will have received a full 80 hours of on-source integration by January 2017 (see Fig. 2). The final reductions of this first batch of 80-hour spectra are scheduled to be publicly released as part of DR2 (September 2017, see Table 5), after they have been processed by our data reduction pipeline and passed our data quality assessment.

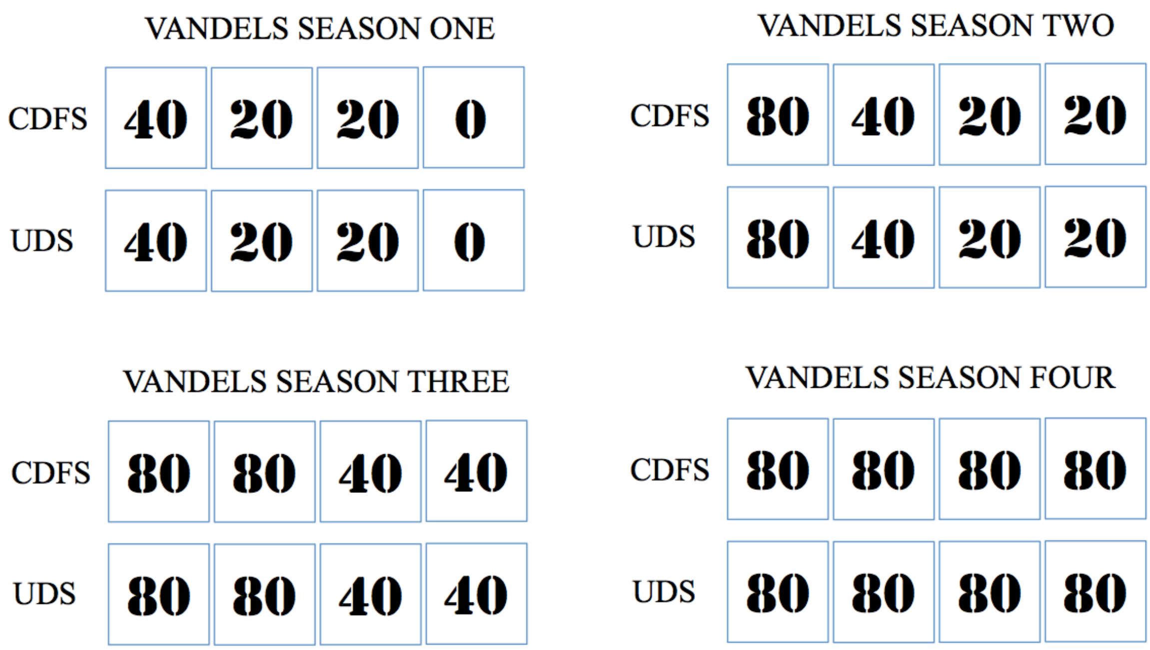

Figure 2: Diagram illustrating our proposed allocation of *on-source* integration time (in hours) to the eight VANDELS pointings (4 in UDS and 4 in CDFS) over a nominal 4-year survey period. At the end of season four, all eight pointings will have obtained 80 hours of on-source integration. Importantly, our adopted strategy ensures that two of the eight pointings will have received their full 80-hour allocation by January 2017.

2.1 Scheduling requirements

Here we evaluate the scheduling requirements for both the pre-imaging and spectroscopic components of VANDELS over a nominal 4-year survey period.

Pre-imaging requirements:
The whole of the VANDELS survey programme will be obtained over a total of only eight VIMOS pointings (4 in CDFS and 4 in UDS) which results in only a modest pre-imaging requirement. At the start of P94 we received 8 hours of $R-$band pre-imaging in service mode. These pre-imaging observations (45 minutes on-source per pointing) ensure an accurate match between the VIMOS and target catalogue astrometry systems. VANDELS should not require further pre-imaging observations unless it proves necessary to re-mount VIMOS on UT3, in which case it is likely that we will require additional pre-imaging.

Table 1: Pre-imaging scheduling and observing requirements

Period	Number of pre-imaging pointings	Filter	Tot. Exp. Time[1] [hrs]	Tot. Exec. Time [hrs]	Observing conditions (seeing/Sky Transparency/Moon)
P94	8	R	6	8	$< 1''$/CLEAR/FLI ≤ 0.5

Table 2: MOS scheduling requirements. In column two we report the number of nights VANDELS observers will be required to staff the telescope (including half nights in August/September and December/January). It should be noted that this is not the number of full nights allocated to VANDELS. The 10 nights scheduled for P94 include 5 half-nights at the end of December shared with the LEGA-C programme, and we assume that the two 12-night runs scheduled during December-January each year (P96, P98, P100 and P102) will also be shared with LEGA-C. The number of observing nights is calculated using EST overhead estimates and observing statistics, which indicate that our requested conditions will be met $\simeq 60\%$ of the time.

Period	N. nights	N. observing runs	N. observers † per run	Average run length
P94	10	2	2	5
P95	17	2	1 & 2	5 & 12
P96	48	4	2	12
P97	17	2	1 & 2	5 & 12
P98	48	4	2	12
P99	17	2	1 & 2	5 & 12
P100	48	4	2	12
P101	17	2	1 & 2	5 & 12
P102	48	4	2	12

† we have assumed that 5-night runs will be staffed by a single observer and that 12-night runs will be staffed by two observers, each covering 6 nights.

Spectroscopy requirements:
To calculate our spectroscopy requirements we explicitly assume that we require dark/grey time (i.e. FLI ≤ 0.5 and moon angular separation $> 75^\circ$), photometric/clear sky conditions and $\leq 1''$ FWHM seeing. In addition to accounting for the frequency of poor seeing and non-photometric/clear conditions, we also assume that we will not observe either of our two fields when they are above an airmass of $\sec z = 1.4$ and that visitor mode is impractical unless we can observe for 4+ hours per night.

The final integration target for VANDELS is 640 hours of on-source exposure time (8 pointings x 80 hours). Based on calculations provided by the ESO survey team (EST), we assume that from a typical 7.5 hour observing block, 2.25 hours will be overheads (i.e. 30%). Consequently, including overheads, we will require a total of 914.2 hours to obtain 640 hours of on-source integration. A provisional schedule for the VANDELS observations over periods P94-P102 is set-out in Tables 2 & 3. This schedule is based upon EST observing statistics which suggest that our required observing conditions will be available $\simeq 60\%$ of the time.

Schedule optimisation:
We note that during December/January it will be possible (and desirable) to share observing runs with the LEGA-C programme targeting the COSMOS field. In the provisional schedule set-out in Tables 2 & 3 we have assumed that the two 12-night runs allocated during December-January in P96, P98, P100 and P102 will be shared with LEGA-C. In P94 we have already been allocated 5 shared nights with LEGA-C at the end of December 2014.

Visitor mode observing runs:
With the exception of the pre-imaging observations, all of the observing for VANDELS will be carried out in visitor mode. Given that VANDELS can make use of both dark and grey time, it would be most efficient to have long observing runs, with an average length of ~ 12 nights during September-January (~ 5 nights in August). In general, we have assumed that 5-night runs will be staffed by a single observer and 12-night runs will require two observers, each staffing the telescope for 6 nights.

2.2 Observing requirements

The instrumental set-up for the main spectroscopic observations is very straightforward. The intention is to observe MOS masks at eight different VIMOS pointings, four in the UDS and four in the CDFS . As a result of our nested slit allocation procedure (see Section 2 for details), we intend to observe four masks at each pointing. In total, over the nominal 4-year duration of the survey, we therefore intend to observe a total of 32 distinct masks (i.e. 128 distinct VIMOS quadrants). Our default instrument set-up for all observations will be identical: MR grism+GG475 order sorting filter, $1''$ slit widths and a minimum slit length of $6''$. Initially we intend to employ individual integration times of 1200s and a dither pattern based on $0.75''$offsets. However, it is possible that we may decide to slightly adjust our observing parameters based on the results of the observations scheduled in P94.

RA distribution and target priorities:
VANDELS will target two fields which are only separated by $\simeq$ 1 hour in RA (UDS: 02:17:38, −05:11:55 and CDFS: 03:32:30, −27:48:28). Overall, both fields have equal priority and will each account for 50% of the total observing time. During October and November, when both fields have good visibility, a typical visitor mode observing run will spend roughly equal amounts of time observing UDS and CDFS. However, in August/September and December/January, it is clear that observations will be focused on the UDS and CDFS respectively.

As highlighted previously (see Fig. 2), our observing schedule will ensure that two of our eight pointings (one in UDS and one in CDFS) will receive their full allocation of 80 hours of on-source integration by the end of the second full observing season.

Meridian transit close to zenith:
From Paranal, one of the two VANDELS target fields (CDFS) transits the local meridian very close to zenith and will therefore be unobservable for $\simeq$ 30 minutes each night due to the rapid change in rotator angle. However, in this instance, having two fields very close in RA is a distinct advantage, and there will be no significant impact on VANDELS observing efficiency. Throughout the September-December observing season it will always be possible to ensure that we are observing the UDS field during the $\simeq$ 30 minutes when CDFS is transiting the local meridian.

During a typical visitor mode observing run, our default strategy will always be to begin observing on the UDS field, before switching to the CDFS after it has transited. By default, we will then observe the CDFS until it reaches an airmass of $\sec z = 1.4$ or the onset of twilight. Over the course of the survey period, this strategy will naturally result in roughly equal amounts of observing time being invested in the UDS and CDFS.

Worst acceptable weather conditions:
As stated previously, in order to guarantee the usefulness of the VANDELS survey as a genuine legacy data set, we require the spectroscopic observations to be obtained in dark/grey time (i.e. FLI ≤ 0.5 and moon angular separation $> 75°$), photometric/clear sky conditions and $\leq 1''$ FWHM seeing. The seeing limit of $\leq 1''$ FWHM and photometric/clear sky conditions are to be regarded as hard limits which, if not met, will result in the telescope being returned to service mode observations. We proposed to re-visit our choice of FLI and moon angular separation constraints at the end of the first full VANDELS observing season.

Table 3: MOS observing requirements. The total exposure time listed in column 6 is the total *on-source* exposure time, whereas the total execution time listed in column 7 includes the recommended EST overhead estimates. The allocation in P94 includes five shared nights with the LEGA-C programme in December 2014. During P96, P98, P100 and P102 we have assumed an allocation of two 12-night runs during December-January which are also shared with LEGA-C. During the shared runs we will require a maximum of 4 VIMOS mask sets.

Period	RA	DEC	N. of distinct mask sets	Grism and filter setup	Tot. exp. time [hrs]	Tot. exec. time [hrs]	Priority	Av. moon constraints
P94	02	-05	1	MR+GG475	13.2	18.7	1	dark/grey
P94	03	-27	2	MR+GG475	13.2	18.7	1	dark/grey
P95	02	-05	2	MR+GG475	17.4	24.8	1	dark/grey
P95	03	-27	2	MR+GG475	17.4	24.8	1	dark/grey
P96	02	-05	3	MR+GG475	59.3	84.8	1	dark/grey
P96	03	-27	3	MR+GG475	59.3	84.8	1	dark/grey
P97	02	-05	2	MR+GG475	17.4	24.8	1	dark/grey
P97	03	-27	2	MR+GG475	17.4	24.8	1	dark/grey
P98	02	-05	3	MR+GG475	59.3	84.8	1	dark/grey
P98	03	-27	3	MR+GG475	59.3	84.8	1	dark/grey
P99	02	-05	2	MR+GG475	17.4	24.8	1	dark/grey
P99	03	-27	2	MR+GG475	17.4	24.8	1	dark/grey
P100	02	-05	3	MR+GG475	59.3	84.8	1	dark/grey
P100	03	-27	3	MR+GG475	59.3	84.8	1	dark/grey
P101	02	-05	2	MR+GG475	17.4	24.8	1	dark/grey
P101	03	-27	2	MR+GG475	17.4	24.8	1	dark/grey
P102	02	-05	3	MR+GG475	59.3	84.8	1	dark/grey
P102	03	-27	3	MR+GG475	59.3	84.8	1	dark/grey
Total					640.0	914.2		

Wind constraints:
VANDELS will be subject to the same wind constraints as all other VLT observations. In the situation where the wind speed exceeds 18 ms^{-1} no observations will be possible and the telescope will close. When the wind speed exceeds 12 ms^{-1} it is necessary to observe $\geq 90^\circ$ away from the wind direction. However, in most situations, it will still be possible to observed either the UDS (Dec$=-5^\circ$) or the CDFS (Dec$=-27^\circ$). On rare occasions when this is not possible, the telescope will return to service mode operations and the time will not be charged to the VANDELS survey.

Quick-look software tools:
It is worth noting that the IASF-Milano team have already developed quick-look reduction software tools for spectroscopic observations with the VIMOS. This software will be available to all VANDELS observers and will allow us to very quickly identify sub-standard data in real-time at the the telescope.

3 Survey data calibration needs

Given the public legacy status of the survey, it is clearly essential that the final data products are as accurately calibrated as possible. Consequently, we have several requirements regarding flat fielding, arc frames and the choice of spectrophotometric standards.

Night time flats and arc calibration frames:
During visitor mode observing runs we will typically execute consecutive long (1.5+ hrs) OBs on either UDS or CDFS masks. We request that sandwiched between the two consecutive UDS or CDFS OBs we are able to obtain night-time flat-field and arc frame calibration data using standard templates.

Choice of spectrophotometric standard stars:
The MR mode spectroscopy observations for VANDELS will provide spectra with a wavelength coverage of 480-1000nm. We are therefore happy to rely on the standard calibration plan, provided that the standard stars are carefully chosen to ensure good flux calibration extending to 1μm. In order to ensure that we are able perform accurate flux calibration extending to 1μm, without being affected by second-order contamination, we have identified suitable red spectrophotometric standard stars (e.g. LTT 3864 & LTT 9239).

4 Data reduction process

VANDELS data reduction will be performed with a fully-automated pipeline, starting from the raw data and flowing down to the wavelength- and flux-calibrated spectra. The pipeline is an updated version of the algorithms and dataflow from the original VIPGI system, fully described in Scodeggio et al. (2005). The original VIPGI system was used to reduce all the spectra from the VVDS (Le Fèvre et al. 2005; Garilli et al. 2008), zCosmos (Lilly et al. 2007) and VUDS surveys (Le Fèvre et al. 2014), while the updated system, called *Easylife*, is being used to reduce all the spectra from the ongoing VIPERS survey (Garilli 2014). In Fig. 3 we provide a block diagram which illustrates the main features of the data reduction pipeline.

A key feature of the data reduction process is the instrument model. Since the four VIMOS quadrants correspond to four physically distinct cameras within the instrument, each quadrant is characterised by its own instrument model and all data reduction procedures are carried out on the data from each quadrant independently. The instrument model consists of three parts:

1. **The optical distortion model:** provides a mapping between positions on the VIMOS focal plane and pixel coordinates on the CCD frame.
2. **The curvature model:** provides a description of the geometrical shape of each spectrum on the CCD, to allow for its tracing and extraction.
3. **The inverse dispersion solution:** provides the mapping between wavelength and pixel coordinates along the geometrical shape traced by the curvature model.

The optical distortion and curvature models are based on accurate determinations of the location of the slit spectra on the CCD frames derived from lamp flats. Using a global instrument model an initial estimate is made of each slit position. Starting from this position, a search is made for the edges of the illuminated area created by the spectrum on the CCD. The shape of these edges is then fitted with a polynomial to provide an updated local determination of the curvature model and a very precise determination of the spectrum position on the CCD.

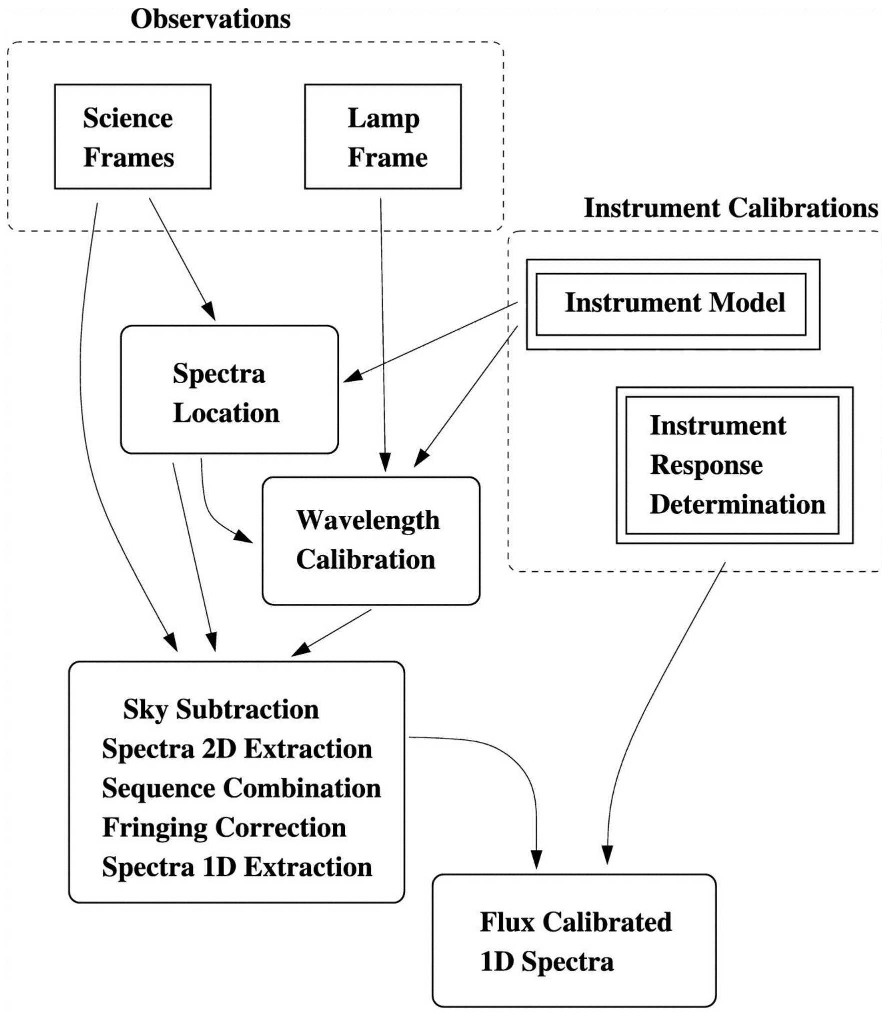

Figure 3: Flow diagram illustrating the key features of the data reduction pipeline.

The inverse dispersion solution is obtained from arc lamp exposures, and employs low-order polynomial fits together with an iterative σ−clipping procedure to compute two-dimensional inverse dispersion solutions for each individual slit. The accuracy of the wavelength calibration is typically ±0.1 pixels, which is equivalent to a median r.m.s residual of 0.25Å for the MR grism employed in VANDELS (Garilli et al. 2014).

The first step in the reduction of VIMOS science data is the canonical preliminary reduction of the CCD frames, which includes prescan level and average bias frame subtraction, trimming of the frame to eliminate prescan and overscan areas, interpolation to remove bad CCD pixels and flat fielding. After the preliminary reduction step, subsequent data reduction steps are carried out on all MOS slits individually. For each individual spectroscopic exposure the wavelength calibration derived from the arc exposures is checked against the positions of bright sky lines and the local inverse dispersion solution modified to account for any discrepancies.

The next steps in the data reduction procedure are the object detection and sky subtraction for each MOS slit spectrum within each individual MOS science exposure. Initially, the slit spectrum is collapsed along the wavelength axis, following the geometrical shape defined by the local curvature model, to produce a slit cross-dispersion profile. A robust determination of the average signal level and r.m.s in this profile is then obtained using an iterative $\sigma-$clipping procedure, and objects are detected as groups of contiguous pixels above a given detection threshold. Before wavelength calibration is applied, a median estimate of the sky spectrum, derived using all the pixels that are devoid of object signal, is subtracted from each slit. The sky spectrum is estimated separately for each individual science exposure due to the significant variation in OH line strength over the timescale of a typical spectroscopic exposure.

The sky-subtracted slit spectra are then two-dimensionally extracted using the tracing provided by the slit curvature model, and resampled to a common linear wavelength scale. Only after this point are the single exposures of a pointing combined together. The N exposures that are part of a pointing are combined together twice. First, the N two-dimensionally extracted spectra for each slit are median combined (with object pixels masked), without taking into account the jitter offsets, to produce a two-dimensional sky-subtraction residual map. The residual map is then subtracted from all the N two-dimensional single-exposure slit spectra, improving the sky-subtraction and removing any residual fringing. At this point a second combination is carried out, this time taking into account the jitter offsets among the N individual two-dimensional slit spectra (as determined during the previous object detection procedure). The single-exposure, residual-map subtracted, spectra are off-set to compensate for the effect of the jitter, and a final average two-dimensional spectrum for each slit is obtained.

The object detection process is repeated on the combined two-dimensional spectra to produce the final catalogue of detected spectra, and a one-dimensional spectrum is extracted for each detected object, using the Horne optimal extraction procedure (Horne 1986). Finally, spectra are flux calibrated using a simple polynomial fit to the instrument response curve derived from observations of spectrophotometric standard stars, and corrected for telluric absorption features. The last correction is based on a template absorption spectrum derived for each combined jitter sequence from the data themselves.

The final flux calibration will be performed by integrating the flux-calibrated spectra under the relevant photometric filter curves and comparing to the high-quality photometry available for each VANDELS target. In this process we will exploit 4-6 photometric bands covering the 480-1000nm wavelength range of the spectra, using a low-order polynomial fit to normalize the spectra to the photometry as a function of wavelength.

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

In this section we provide details of our strategy for staffing the visitor mode observing runs required by the VANDELS survey, a detailed breakdown of the team responsibilities (including allocated FTE) and the hardware/software available for OB preparation, data reduction and data archive ingestion.

Observers:
According to the provisional observing schedule discussed in Section 2.1 we anticipate that, over a ~4-year period, the VANDELS survey will require $\sim$ 26 visitor mode observing runs. We intend to execute the vast majority of the VANDELS observing using a small team of dedicated observers. The observing team of will commit to undertaking 3-4 VANDELS observing runs over the ~4-year duration of the survey. The members of the observing team will be drawn from Co-Is actively working with the VANDELS data, who have a personal investment in ensuring that the data quality is as high as possible. Those individuals who have already indicated there availability to join the observing team are highlighted in the full VANDELS Co-I list on page 16.

Team responsibilities:
The overall responsibility for both the successful execution of the survey and the distribution of the final data products to the community will be shared by McLure and Pentericci as VANDELS Co-PIs. The Co-PIs will be supported by the members of the VANDELS management group (Dunlop, Fontana, Nandra, Elbaz & Cimatti) who have been chosen on the basis of their multi-wavelength expertise and their previous experience in managing large ESO projects (e.g. GOODS, Ultra-VISTA, K20, GMASS & UDSz).

To ensure the successful planning and execution of the VANDELS survey, we have constructed small teams to focus on specific tasks. Below we list the tasks allocated to each team, together with those individuals who will coordinate each team's efforts. Additional team members drawn from the full Co-I list (see page 16) are not explicitly listed.

1. Target selection team
Members: S. Finkelstein • A. Grazian • R. Bowler • M. Cirasuolo • M. Bolzonella
The members of this team will be responsible for producing robust target catalogues from the available multi-wavelength imaging in the UDS and CDFS fields to be used in VIMOS slit allocation. Together they will produce consolidated catalogues of potential targets based on independent measurements of the photometric redshift probability functions.

2. VIMOS mask production team
Members: A. Iovino • M. Nonino • O. Cucciati
The members of this team will be responsible for the necessary VANDELS pre-imaging and using VMMPS to optimally allocate slits based on the information supplied by the target selection team.

3. Survey management team
Members: E. Marmol-Queralto • A. Bongiorno • E. Curtis-Lake • M. Castellano • J. Mendez-Abreu
E. Marmol-Queralto and A. Bongiorno will take joint responsibility for the day-to-day survey management. They will be assisted in the organisation and supervision of the VANDELS visitor observing programme by the other members of the team.

4. Data Reduction team
Members: B. Garilli • M. Scodeggio • P. Franzetti
The members of this team will be responsible for the full data-reduction process, taking the raw data and producing fully wavelength-calibrated and flux-calibrated 1D and 2D spectra using the VIPGI and Easylife software developed in IASF-Milano. P. Franzetti will have overall responsibility for ensuring that the data products delivered to ESO are phase 3 compliant. In addition to the staff listed here, IASF-Milano will employ a dedicated post-doctoral researcher (in-post by September 2015) to work on the VANDELS data reduction pipeline.

5. Data quality and redshift measurement team
Members: E. Vanzella • F. Cullen • I. Balestra • L. Guaita • P. Popesso • K. Caputi • W. Hartley
The members of this team will be responsible for monitoring the quality of the spectra as they are obtained. Subsequently, this team will be responsible for redshift determination using a combination of automated algorithms and detailed visual inspection.

6. Enhanced data products
Members: V. Sommariva • G. Cresci • A. Mortlock • N. Bourne • R. Amorin • S. Charlot • M. Mignoli • M. Talia • A. Galametz
The members of this team will be responsible for the production and dissemination of value-added data products, in addition to the basic 1D+2D spectra and associated redshifts. These data products will include line flux and EW measurements, together with basic stellar-population parameters derived from SED fitting.

Table 4: Summary of the team responsibilities, including the allocated FTE.

Name	Function	Affiliation	Country	FTE
R. McLure	Co-PI	University of Edinburgh	UK	0.5
L. Pentericci	Co-PI	INAF, Rome	Italy	0.5
J. Dunlop	Management Group	University of Edinburgh	UK	0.1
A. Fontana	Management Group	INAF, Rome	Italy	0.1
K. Nandra	Management Group	MPE	Germany	0.1
D. Elbaz	Management Group	CEA	France	0.1
A. Cimatti	Management Group	University of Bologna	Italy	0.1
S. Finkelstein	Target selection	University of Texas	USA	0.1
A. Grazian	Target selection	INAF, Rome	Italy	0.1
R. Bowler	Target selection	University of Edinburgh	UK	0.1
M. Cirasuolo	Target selection	University of Edinburgh	UK	0.1
M. Bolzonella	Target selection	INAF, Bologna	Italy	0.1
A. Iovino	Mask production	INAF, Brera	Italy	0.2†
M. Nonino	Mask production	INAF, Trieste	Italy	0.2†
O. Cucciati	Mask production	University of Bologna	Italy	0.2†
E. Marmol-Queralto	Survey Manager	University of Edinburgh	UK	0.3
A. Bongiorno	Survey Manager	INAF, Rome	Italy	0.3
E. Curtis-Lake	Observation supervision	University of Edinburgh	UK	0.2
M. Castellano	Observation supervision	INAF, Rome	Italy	0.2
J. Mendez-Abreu	Observation supervision	University of St. Andrews	UK	0.1
New Post-doc	Data reduction pipeline	IASF-Milano	Italy	1.0
B. Garilli	Data reduction pipeline	IASF-Milano	Italy	0.2†
M. Scodeggio	Data reduction pipeline	IASF-Milano	Italy	0.2†
P. Franzetti	Survey web site/Phase-3 compliance	IASF-Milano	Italy	0.2†
F. Cullen	Data quality + redshift determination	University of Edinburgh	UK	0.2
L. Guaita	Data quality + redshift determination	INAF, Rome	Italy	0.2
E. Vanzella	Data quality + redshift determination	INAF, Bologna	Italy	0.1
I. Balestra	Data quality + redshift determination	INAF, Trieste	Italy	0.1
P. Popesso	Data quality + redshift determination	MPE	Germany	0.1
K. Caputi	Data quality + redshift determination	Groningen	Netherlands	0.1
W. Hartley	Data quality + redshift determination	ETH	Switzerland	0.1
R. Amorin	Enhanced data products	INAF, Rome	Italy	0.2
A. Mortlock	Enhanced data products	University of Edinburgh	UK	0.2
V. Sommariva	Enhanced data products	University of Bologna	Italy	0.1
G. Cresci	Enhanced data products	INAF, Arcetri	Italy	0.1
N. Bourne	Enhanced data products	University of Edinburgh	UK	0.1
S. Charlot	Enhanced data products	IAP	France	0.1
M. Mignoli	Enhanced data products	INAF, Bologna	Italy	0.1
M. Talia	Enhanced data products	University of Bologna	Italy	0.1
A. Galametz	Enhanced data products	MPE	Germany	0.1

† 0.2 FTE in the first year of the survey, 0.1 FTE thereafter.

References:

Garilli et al. 2008, A&A, 486, 683• Garilli et al. 2012, PASP, 124, 1232• Garilli et al. 2014, A&A, 563, 92• Hammersley et al., 2013, Msngr, 151, 2• Horne, 1986, PASP, 98, 609• Le Fèvre et al. 2005, A&A, 439, 845 • Le Fèvre et al. 2014, arXiv:1403.3938• Lilly et al. 2007, ApJS, 172, 70• Sánchez-Janssen et al., 2014, A&A, 566, 2• Scodeggio et al. 2005, PASP, 117, 1284

Hardware:
Due to the nature of the VANDELS survey (i.e. long integrations on only eight VIMOS positions) the data volume is not large by modern survey standards. Specifically, assuming individual integrations of 1200s, the 640 hours of on-source integration for VANDELS will require the reduction of 4x1920=7680 VIMOS quadrants. Over a 4-year survey this corresponds to a relatively modest data flow rate and all of the data reduction will be carried out on a dedicated linux machine (> 1Tb disk space) at IASF-Milano which will also host the VANDELS website (`vandels.inaf.it`).

Similarly, because we are only required to prepare a total of 32 VIMOS masks (i.e. 8 pointings, 4 masks per pointing) over a 4-year period, the hardware requirement for mask preparation is also modest. It is intended that mask preparation will be carried out on standard linux desktop machines by the members of the mask production team (see Table 4).

Software:
The members of the mask production and observation supervision teams are all experienced with the P2PP3 and VMMPS software packages. The data reduction team at IASF-Milano wrote the original data reduction software for VIMOS (VIPGI) and its successor *Easylife*. These software packages are currently being used at IASF-Milano to reduce the VIMOS data from the on-going VIPERS survey. Through their experience with VIPERS (and previously with VVDS, zCOSMOS and VUDS), the data reduction team are familiar with phase-3 compliance regulations and the requirements for successful ingestion of data to the ESO data archive. Finally, the IASF-Milano team have developed quick-look reduction software which will be available to all VANDELS observers and will be indispensable for identifying data problems in real time at the telescope.

6 Data quality assessment process

We will implement a data quality control scheme following the successful system currently being employed for the VIPERS survey (Garilli et al. 2014). This system carefully monitors the observing conditions for each scientific exposure. The seeing is directly measured from the raw spectroscopic data using bright reference objects. In addition, the median airmass of each exposure is computed on the basis of the observation hour angle and the airmass at the start and end of the observation. Moreover, the mean sky level is also measured and stored on an exposure basis. Finally, the accuracy of the individual slit wavelength calibrations computed via the inverse dispersion solutions is also monitored. All these data quality metrics are recorded in the FITS header of each individual spectrum.

As all of the final VANDELS spectra will be a combination of many individual exposures, the mean value of these parameters will be computed during spectra combination (see Section 4). An error spectrum, which takes into account poisson statistics as well as sky subtraction errors is computed following the prescription given in Garilli et al. (2014), and will be delivered together with the final data products.

Throughout the survey, all of these parameters will be stored in a dedicated reduction database on an exposure by exposure basis. In the case of slit dependent values, such as wavelength calibration r.m.s. and sky level, a median value per quadrant per exposure will be computed and recorded. Diagnostic plots showing the temporal behaviour of these parameters will be made after each observing run. Observations showing some statistically significant deviation from the mean will be flagged and their further use will be subject of closer scrutiny, manually carried out by the reduction team.

7 External Data products and Phase 3 compliance:

In the following description we have split the VANDELS data products into basic and enhanced categories. The basic data products are those which could be regarded as the minimum required for a spectroscopic survey of this nature. The basic data products for a given object will be made available at the scheduled data release (see Table 5) following the completion of that object's allocated on-source integration time (i.e. 20, 40 or 80 hours). The enhanced data products are those which the team is committed to delivering as an additional service to the community, and are designed to maximize the scientific productivity and legacy value of VANDELS. The enhanced data products will form part of the final VANDELS data release (see Table 5). For the final VANDELS data release, we are prepared to fully re-process the spectroscopic data if this is merited by improvements to the data reduction process over the course of the VANDELS survey.

We note that, throughout the survey, each VANDELS target will be allocated a unique target identifier and precise coordinates. All data products associated with a given object (including all catalogue entries) will be tagged with the same unique target identifier and coordinates. In addition, we are also prepared to introduce an additional KEYWORD to identify whether each target has been allocated 20, 40 or 80 hours of on-source integration. Finally, all data catalogues (including redshifts, emission/absorption line features and derived physical properties from SED fitting) will be formatted according to the Phase 3 data standard for tabular data.

In order to be compliant with ESO public survey policy, all data products listed here will be delivered for publication from the ESO archive via Phase 3. In addition, it is our intention to also make the data products available to the community via our dedicated VANDELS website (`vandels.inaf.it`).

Basic Data Products

- **Final extracted one-dimensional (1D) spectra**

The final wavelength-calibrated and flux-calibrated 1D spectra for all objects targeted by VANDELS. In addition to flux calibration using spectrophotometric standards, the final flux calibration will be normalised to the multi-wavelength photometry available for each target. According to the requirements of the ESO Science Data Products standard (SDP) document, the 1D spectrum of each object will be delivered in binary table format, with a monotonically increasing wavelength axis and a flux scale in physical units (e.g. erg/s/cm^2/Å). In addition to the object spectrum, the binary table for each object will also contain the associated noise and sky spectrum.

- **Final stacked two-dimensional (2D) spectra**

The final wavelength-calibrated 2D spectrum for each target will be made available. The 2D spectra will be essential for confirming the reality of faint emission features and identifying potential emission-line velocity gradients. The final 2D spectra will also be delivered in a format compliant with the ESO SDP.

- **Spectroscopic redshift catalogue**

A final catalogue will be made available which contains the essential information for each VANDELS target: ID, RA, Dec, I-magnitude, H-magnitude, spectroscopic redshift and redshift quality flag. The redshift quality flag will be defined on the same system previously employed by the VVDS and zCOSMOS surveys. This catalogue will be delivered in compliance with the ESO SDP regulations for science catalogue data.

Intermediate Data Products

In addition to the data products associated with completed spectra, at each data release we also intend to release intermediate level data products. The intermediate level data products will consist of fully reduced 1D and 2D spectra in sub-sets of 20 hours of on-source integration. For example, for a target which has been allocated a total on-source integration time of 80 hours, at the appropriate data release milestone we will release reduced spectra consisting of 20, 40 and 80 hours of integration (see Table 6). All intermediate data products will also be delivered in a format compliant with ESO SDP regulations.

Enhanced Data Products

• VANDELS selection function

We intend to make available all of the relevant information necessary to compute the VANDELS selection function. This information will allow the community to accurately calculate the completeness of the survey for their own scientific purposes.

• Final combined spectroscopic redshift+photometric catalogue

In addition to the final spectroscopic redshift information, this catalogue will feature aperture-matched optical+nearIR photometry for each target. Based on this information the community should be able to directly proceed to SED fitting using their preferred choice of software and templates.

• Basic stellar population parameters

Based on the final redshift+photometric catalogue we will release our own catalogue of basic stellar population parameters (e.g. stellar mass, age & reddening) derived by fitting standard templates (e.g. Bruzual & Charlot 2003 + Chabrier IMF).

• Final catalogue of spectroscopic measurements

In addition to the final spectroscopic redshift determinations, a catalogue will be made available to the community which contains line flux and equivalent width measurements (together with error estimates and data quality flags) for robustly detected emission/absorption features in each VANDELS spectrum.

8 Timeline delivery of data products to the ESO archive:

In Table 5 we present the timeline for the VANDELS survey, including the provisional schedule for public data releases via the ESO archive. In the timeline we assume that the first VANDELS data release via the ESO archive will be in September 2016, with further data releases occurring at yearly intervals, until data release four (DR4) in September 2019. In addition, we have scheduled a final data release (DR5) for June 2020, which will feature all of the enhanced data products and potentially a full re-reduction of the VANDELS spectroscopic dataset. As described in Section 2, our observing strategy means that each VANDELS target will be allocated 20, 40 or 80 hours of on-source integration. At each data release, we intend to provide the final reduced spectroscopic data for all objects whose spectroscopic observations were *completed* at the end of the previous observing season (DR1 will also include data from two P94 observing runs scheduled for Nov/Dec 2014). For a given target, the spectrum is considered to have been completed when that target has received its full allocation of on-source integration time (i.e. 20, 40 or 80 hours). In addition, at each data release we also intend to provide reduced spectra for those 40-hour targets which have received 50% of their allocation and those 80-hour targets which have received 25% or 50% of their allocation. It is clear from Table 5 that the timescale between obtaining the data and releasing it via the ESO archive is short (i.e. 8 months). As a consequence, it has been agreed with the EST that if it proves impossible to satisfy the data release timescale, we are obliged to provide a report on the status of the spectroscopic data, including signal-to-noise estimates, which will be made available to the public.

According to the observing schedule outlined in Section 2, and illustrated in Fig. 2, we can calculate the number of completed and partially completed spectra we expect to release at each data release. This information is provided in Table 6.

Month	Year	Milestone
November	2014	**Start of VANDELS**
September	2015	**VANDELS observing season one (START)**
January	2016	**VANDELS observing season one (END)**
September	2016	**First VANDELS data release (DR1)**
September	2016	**VANDELS observing season two (START)**
January	2017	**VANDELS observing season two (END)**
September	2017	**Second VANDELS data release (DR2)**
September	2017	**VANDELS observing season three (START)**
January	2018	**VANDELS observing season three (END)**
September	2018	**Third VANDELS data release (DR3)**
September	2018	**VANDELS observing season four (START)**
January	2019	**VANDELS observing season four (END)**
September	2019	**Fourth VANDELS data release (DR4)**
June	2020	**Final VANDELS data release (DR5)**

Table 5: Provisional timeline highlighting the major milestones over the course of the VANDELS survey.

		No. of completed spectra			No. of partially complete spectra			
Data release	Date	20-hrs	40-hrs	80-hrs	40-hrs(50%)	80-hrs(25%)	80-hrs(50%)	Total
DR1	Sept 2016	160	160	0	320	320	160	1120
DR2	Sept 2017	320	480	160	320	320	160	1760
DR3	Sept 2018	480	960	320	0	0	320	2080
DR4	Sept 2019	640	1280	640	0	0	0	2560

Table 6: A summary of the numbers of completed and partially completed spectra we expect to release as a function of data release schedule and integration time. Columns 6-8 list the number of 40-hr and 80-hr objects for which, at the data release of interest, we intend to release a reduction based on 25% or 50% of the total integration time.

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