European Organisation for Astronomical Research in the Southern Hemisphere

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APPLICATION FOR OBSERVING TIME

PERIOD: **102A**

Important Notice:

By submitting this proposal, the PI takes full responsibility for the content of the proposal, in particular with regard to the names of CoIs and the agreement to act according to the ESO policy and regulations, should observing time be granted.

1. Title

Category: **A–3**

VISTA-VIPERS: is cosmic shear in tension with Planck?

2. Abstract / Total Time Requested

Total Amount of Time:

We propose to obtain near-IR fluxes of some 100,000 galaxies in deep spectroscopic survey fields with VISTA. The aim is two-fold: **(i)** Establish *the* reference data set for cross-correlation techniques to calibrate photometric redshifts – the backbone of current and future weak lensing surveys. These measurements are particularly timely in view of the current KiDS and DES results which consistently find a lower clustering amplitude of large-scale structure than Planck: the dominant systematic error on this result is the photo-z calibration. VISTA data on VIPERS and VVDS will increase the existing overlap area between deep spectroscopy and near-IR photometry tenfold, and remove this bottleneck for cosmic shear surveys. **(ii)** Obtain accurate SEDs for these galaxies for studies of stellar masses, stellar population ages and dust content down to a mass of $M_* \sim 10^{10} M_\odot$ at $z \sim 1$. This proposal was approved in P100 and every field observed, but only in half of the required filters.

3.

Run	Period	Instrument	Time	Month	Moon	Seeing	Sky	Mode	Type
A	102	VIRCAM	12.5h	oct	g	1.2	THN	s	
B	102	VIRCAM	3.8h	oct	n	1.2	THN	s	

4.

Number of nights/hours	Telescope(s)	Amount of time
a) already awarded to this project:	VISTA	30h awarded in P100; 13.7h were executed.
b) still required to complete this project:		

5. Special remarks:

More than half of the associated optical observations of the same fields with VST have already been obtained; the remainder are in the KiDS public survey queue and will be completed by the end of P102.

6. Principal Investigator: KKUIJKEN

6a. Co-investigators:

H.	Hildebrandt	1108
M.	Bilicki	1716
A.	Edge	1237
T.	Erben	1108

Following CoIs moved to the end of the document ...

7. Description of the proposed programme

A – Scientific Rationale: Our cosmological model, ΛCDM, is sufficiently strange that, despite its great success describing the Universe, it warrants stringent testing. Gravitational lensing by large scale structure, a.k.a. cosmic shear, is one of the most direct probes that we can use. Cosmic shear surveys have now progressed to the point that the accuracy with which they measure the relevant cosmological parameters can compete with the best other probes, including CMB experiments. In particular lensing can precisely measure the amount of clustered matter, summarized in the parameter $S_8 \equiv \sigma_8\sqrt{\Omega_m/0.3}$. Intriguingly, most cosmic shear measurements (but not all) measure S_8 values that are significantly lower than what is predicted by the best-fit ΛCDM model from the Planck CMB mission (Kilbinger et al. 2015).

Combining galaxy shape measurements with photometric redshifts (photo-z) adds the vital 3D information that sets the physical scale for the observed weak lensing distortions (the amplitude of the weak lensing distortion depends on the angular diameter distances to lens and source). Knowing the redshift *distribution* of the lensed galaxies is essential, even if individual photo-z are noisy. To achieve the necessary percent-level accuracy on the mean redshifts, calibrating these $N(z)$'s against spectroscopic redshifts is unavoidable.

The most recent cosmic shear measurement, shown in green in Fig. 1, is from an analysis of the first one-third of the data from our ESO-led Kilo-Degree Survey (KiDS) on the VST (Kuijken et al 2015; Hildebrandt et al. 2017 ≡ H17), and its constraints on S_8 are in tension at the $\sim 2.5\sigma$ level with Planck (2015). The competing Dark Energy Survey have since reported similar, if slightly less discrepant, results (Troxel et al 2017). KiDS observations continue, with analysis of a data set double the size of H17 (some 900 square degrees) underway in preparation for the 4th KiDS data release, due before the end of 2018. DR4 will include near-infrared photometry from the overlapping, completed, VIKING survey on VISTA.

In H17 we have classified KiDS galaxies into four tomographic bins, based on the best-fit template-fitting photo-z using the well-known BPZ code. There are two possible strategies for obtaining the $N(z)$ for each of these bins: directly reweighting spectroscopic redshift catalogues so that they reproduce the distribution of galaxy magnitudes and colours using a k-nearest-neighbour technique (DIR); or cross-correlating KiDS galaxy positions with thin redshift slices of an overlapping spectroscopic redshift catalogue and thus deducing the fraction of KiDS galaxies at each redshift (CC). The methods are complementary. DIR requires a very deep spectroscopic redshift catalogue that spans the full magnitude range of the KiDS galaxies; on the other hand CC requires a very large galaxy population that overlaps in redshift, but does not have to be as deep as the reference sample. In the KiDS-450 analysis our CC calibration relied on just 1.5 square degrees of suitable spectroscopic data, and the errors (grey contours in Fig. 1) were consequently large. Only optical data were used.

B – Immediate Objective:

Our immediate objective is to firm up the calibration of the photo-z for KiDS, for both the CC and DIR approaches. Such an improvement is necessary to (i) ensure proper validation of the KiDS-450 calibration, and (ii) prepare for the next installment of KiDS and other cosmic shear surveys, where the requirements on the photo-z are even more stringent.

Specifically, we will (i) bring the accuracy of the CC calibration into line with what we achieved with DIR, by incorporating large-area spectroscopic fields; (ii) reduce the sensitivity of the DIR method to sample variance by adding two widely separated deep calibration fields; and (iii) improve the overall quality of the photo-z estimates (used to define the tomographic bins) by including VIKING data (see Fig. 2), which will enable us to define a fifth tomographic bin beyond redshift 0.9. Adding this fifth high-z bin will increase the volume and hence the statistical power of KiDS by an estimated 20%.

Rather than embarking on a massive spectroscopic survey of KiDS galaxies, it is much more efficient to obtain KiDS- and VIKING-like photometry for areas of the sky where such redshifts have already been obtained. Bringing the CC accuracy to the level of DIR (see Fig.1) requires a tenfold increase in the area covered with deep spectra, from 1.5 to 15 sq.deg. At $z \lesssim 0.7$ we can use the GAMA, BOSS, and 2dFLenS (Blake et al 2016) surveys, which overlap with KiDS/VIKING observations, but beyond this redshift limit new data are required. The VIPERS survey (Scodeggio et al 2018) is ideal for this purpose: it covers a large area, its depth of I=22.5 is well-matched to KiDS, and its photometric preselection ensures that it contains mostly galaxies between redshifts 0.5 and 1.2 (Fig. 3). The VVDS (LeFevre et al 2013) shares a lot of these properties and adds more lines-of-sight to reduce the crucial sample variance in this calibration sample.

For all fields mentioned above (from VIPERS and VVDS) KiDS observations are already scheduled on the VST and being taken; here we request the corresponding VIKING-like VISTA data.

Apart from the cosmology science case outlined above, near-IR imaging data on VIPERS has significant legacy value. Some useful WIRCAM coverage exists (mostly *Ks* band, Moutard et al 2016a,b), but the proposed 5-band VISTA data will significantly improve the stellar mass estimates for VIPERS galaxies (Davidzon et al. 2013), and hence of the stellar mass function out to redshift 1 for galaxies down to $10^{10} M_\odot$.

References: Blake et al 2016, MN 462, 4240; Davidzon et al 2013, A&A, 558, 23; Hildebrandt et al 2017, MN 465, 1454 (H17); Kilbinger 2015, RPPh 78, 6901; Kuijken et al 2015, MN 454, 3500; LeFevre et al 2013, A&A 559, 14; Moutard et al 2016a/b, A&A 590, 102/3; Planck Collaboration 2015, A&A 594, 13; Scodeggio et al 2018, A&A 609, A84; Troxel et al 2017, arXiv:1708.01538

7. Description of the proposed programme and attachments

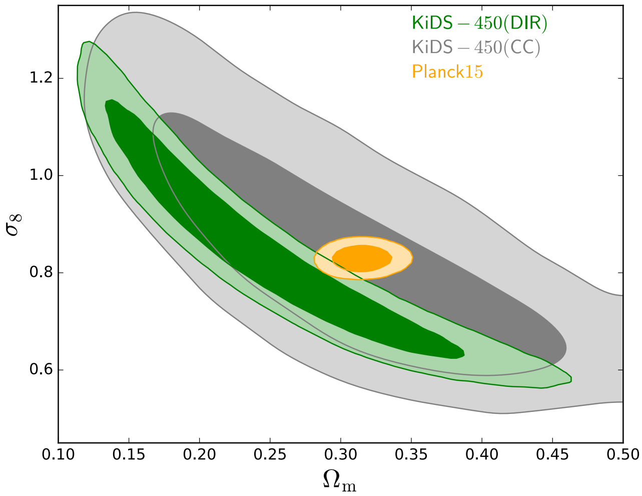

Fig. 1: Cosmology constraints from KiDS-450 using the different photometric redshift calibration strategies. Note the tension between Planck and the most precise (DIR) calibration. The aim of this proposal is to reduce the CC errors by a factor of $\sqrt{10}$ to bring them in line with the DIR calibration accuracy, and to prepare for the analysis of the next, twice as extensive, KiDS lensing data.

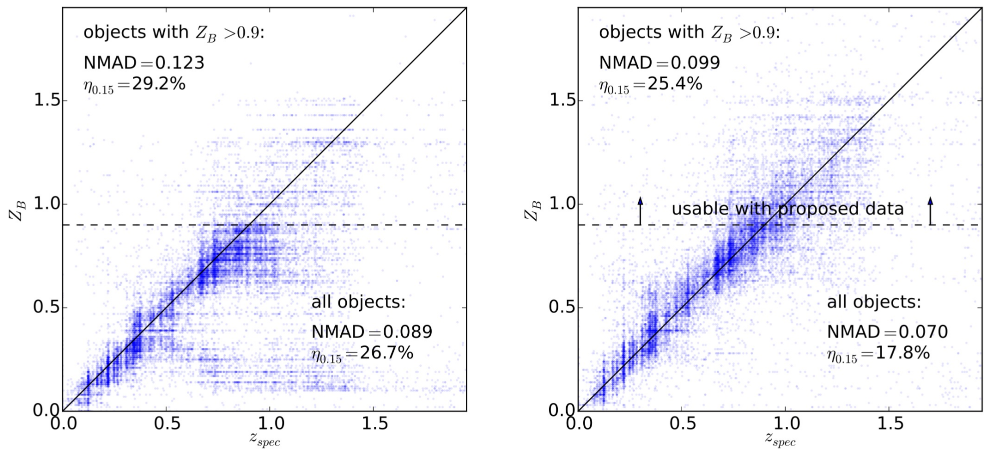

Fig. 2: Photo-z (Z_{B}) vs. spectroscopic redshifts using optical-only *ugri* data as in H17 (*left*) and using *ugriZYJHKs* optical + near-infrared data (*right*) including ESO DDT data and an updated BPZ setup. The numbers correspond to the normalised median-absolute-deviation (NMAD) of the quantity $(z_{\mathrm{spec}} - Z_{\mathrm{B}})/(1 + z_{\mathrm{spec}}) \equiv \Delta z/(1+z)$ and the rate of objects with $|\Delta z/(1+z)| > 0.15$ for all objects as well as for objects with photo-z $Z_{\mathrm{B}} > 0.9$ (i.e. the new 5th tomographic bin). The near-infrared data improve on all of these statistics, in particular for high-redshifts that weren't used in H17 but will be usable with the data from this proposal. They will also provide essential training data for machine-learning, see Bilicki et al. (2017, arXiv:1709.04205).

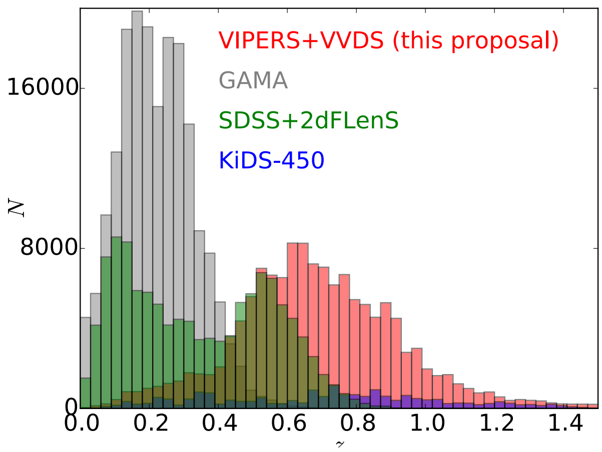

Fig. 3: Numbers of spectroscopic redshifts available in GAMA (grey), VIPERS and VVDS (red), SDSS-BOSS and 2dFLenS (green) vs. the number that were used in the KiDS-450 CC calibration of Hildebrandt et al. (2017). GAMA, SDSS, and 2dFLenS overlap with KiDS and will be used at $z < 0.7$; with the proposed KiDS/VIKING-like imaging of the VIPERS and VVDS areas we will be able to do the same at higher redshift.

8. Justification of requested observing time and observing conditions

Lunar Phase Justification: No restrictions on the lunar phase are required for observations in the H- and Ks-bands. For Z and Y we require grey time, and we split the J-band exposures into two halves, one half in grey time and one half without restrictions. This follows closely the VIKING observing strategy.

Time Justification: (including seeing overhead) We have requested the number of hours required to observe a single VISTA 'tile' over each of the target fields listed in Sect. 11, using the same observation strategy as is implemented in VIKING. Total exposure times and magnitude limits per filter in VIKING are:

filter	exp. time [s]	lim.mag. (5σ AB $2''$)
Z	480	22.7
Y	400	22.0
J	400	21.8
H	300	21.1
Ks	480	21.2
total	2060	

In order to attain these exposure times over a uniform area requires a six-step dither strategy that results in the majority of the area being covered by two dithers. Hence the required time on the telescope is three times as large, 6180s. With overheads we expect to be able to observe each field in 2.5h resulting in a total time request of 30h for our program. This time estimate is directly based on the most recent version of VIKING OBs.

(Note that, as for the VIKING main survey, the OB's have an executing time that slightly exceeds the 1h limit. In the interests of efficiency we will therefore request the same waiver that was granted for the VIKING observations.)

8a. Telescope Justification:

The purpose of these observations is to create an optical+near-IR KiDS+VIKING equivalent dataset covering multiple fields with existing deep spectroscopic redshift data. As such, we require observations to be done using the same instruments, observing strategy and sky conditions, as KiDS and VIKING. Optical *ugri* KiDS-like observations of the fields are already in the VST queue. This request covers the corresponding $ZYJHKs$ VIKING-like VISTA observations.

8b. Observing Mode Justification (visitor or service):

N/A

8c. Calibration Request:

Standard Calibration

9. Report on the use of ESO facilities during the last 2 years

This proposal is part of the KiDS public survey team's effort to measure the growth of large-scale structure from weak lensing, and to use this information to study the cosmological model. KiDS+VIKING has been ongoing on the VST and VISTA for the past six years, and has resulted in over 35 papers already (see http://kids.strw.leidenuniv.nl/papers.php): most pertinent to this proposal are the papers by Hildebrandt et al. (2017) and Joudaki et al. (2017), which show our cosmology constraints based on the first 450 square degrees of KiDS-only lensing data. Analysis of 900 square degrees of KiDS+VIKING is now underway, and will require the added fidelity of the photometric redshift calibration that the present proposal enables.

All KiDS and VIKING data are released via the ESO archive and publicly available.

A DDT proposal, similar to this one but observing only two tiles (overlapping with the DEEP2 redshift survey), was approved in November 2016. The data have been analysed and included in the KiDS+VIKING photo-z calibration. The results in the right-hand panel of Fig. 2 are directly based on these data.

This proposal was accepted for P100 but only 45% executed. Unfortunately the data resulted in only one further pointing with complete ZYJHKs coverage. This proposal will increase that number to 12.

9a. ESO Archive - Are the data requested by this proposal in the ESO Archive (http://archive.eso.org)? If so, explain the need for new data.

Compared to our P100 submission, we have removed the completed OBs and reduced the requested time accordingly. We have taken account of the existing VIDEO data that covers part of W1 where we can.

We have also checked the CFHT WIRCAM archive. WIRCAM has a 4x smaller footprint than VIRCAM, but it has also been used to cover parts of VIPERS. *Ks* band coverage exists for VIPERS DR1, as well as somewhat too shallow Y band observations and sporadic shallow J and H images. We considered skipping *Ks* band in this proposal, but prefer to ensure instrumental homogeneity as well as the more robust photometric calibration that is possible with the larger VISTA footprint. Our VVDS fields have no WIRCAM coverage.

9b. GTO/Public Survey Duplications:

Our fields intentionally overlap with VST optical imaging of the same regions (undertaken as part of the Kilo-Degree Survey), in order to build full 9-band photometric data.

Note that VHS public survey data from VISTA cover some of our target areas too, but the observations are much too shallow for our needs (nor do they include ZY).

10. Applicant's publications related to the subject of this application during the last 2 years

de Jong et al. 2017, A&A, 604, A134: **The third data release of the Kilo-Degree Survey**

Hildebrandt et al. 2017, MNRAS, 465, 1454: **KiDS-450: Cosmological parameter constraints from tomographic weak gravitational lensing**

Brouwer et al. 2017, MNRAS, 466, 2547: **First test of Verlinde's theory of emergent gravity using weak gravitational lensing measurements**

Tröster et al. 2017, MNRAS, 467, 2706: **Cross-correlation of weak lensing and gamma rays: implications for the nature of dark matter**

Morrison et al. 2017, MNRAS, 467, 3576: **the-wizz: clustering redshift estimation for everyone**

Van Uitert et al. 2017, MNRAS, 467, 4131: **Halo ellipticity of GAMA galaxy groups from KiDS weak lensing**

Dvornik et al. 2017, MNRAS, 468, 3215: **A KiDS weak lensing analysis of assembly bias in GAMA galaxy groups**

Joudaki et al. 2017, MNRAS, 471, 1259: **KiDS-450: Testing extensions to the standard cosmological model**

Harnois-Déraps et al. 2017, MNRAS, 471, 1619: **KiDS-450: tomographic cross-correlation of galaxy shear with Planck lensing**

Koehlinger et al. 2017, MNRAS, 471, 4412: **KiDS-450: the tomographic weak lensing power spectrum and constraints on cosmological parameters**

Velliscig et al. 2017, MNRAS, 471, 2856: **Galaxy-galaxy lensing in EAGLE: comparison with data from 180 deg^2 of the KiDS and GAMA surveys**

Joudaki et al. 2018, MNRAS, 474, 4894: **KiDS-450 + 2dFLenS: Cosmological parameter constraints from weak gravitational lensing tomography and overlapping redshift-space galaxy clustering**

Van Uitert et al. 2018, MNRAS, in press (arXiv:1706.05004): **KiDS+GAMA: Cosmology constraints from a joint analysis of cosmic shear, galaxy-galaxy lensing and angular clustering**

11. List of targets proposed in this programme

Run	Target/Field	α(J2000)	δ(J2000)	ToT	Mag.	Diam.	Additional info	Reference star
A	VVDSF10	10 04 20	02 00 00	1.25		1.5d	1 Ptg., ZYJ (JHKs done)	
A	VVDSF22	22 18 00	-00 06 00	1.25		1.5d	Ptg. 1/2, ZYJ (JHKs done)	
A	VVDSF22	22 18 00	00 54 00	1.25		1.5d	Ptg. 2/2, ZYJ (JHKs done)	
A	VIPERS-W1	02 07 36	-04 37 30	1.25		1.5d	Ptg. 2/5, ZYJ	
B	VIPERS-W1	02 07 36	-04 37 30	1.25		1.5d	Ptg. 2/5, JHKs	
A	VIPERS-W1	02 13 36	-04 37 30	1.25		1.5d	Ptg. 3/5, ZYJ	
B	VIPERS-W1	02 13 36	-04 37 30	1.25		1.5d	Ptg. 3/5, JHKs	
A	VIPERS-W1	02 25 36	-05 37 30	1.25		1.5d	Ptg. 4/5, ZYJ	
B	VIPERS-W1	02 25 36	-05 37 30	1.25		1.5d	Ptg. 4/5, JHKs	
A	VIPERS-W1	02 31 36	-04 37 30	1.25		1.5d	Ptg. 5/5, ZYJ (JHKs done)	
A	VIPERS-W4	22 03 08	01 52 00	1.25		1.5d	Ptg. 1/3, ZYJ (JHKs done)	
A	VIPERS-W4	22 09 00	01 52 00	1.25		1.5d	Ptg. 2/3, ZYJ (JHKs done)	
A	VIPERS-W4	22 14 50	01 52 00	1.25		1.5d	Ptg. 3/3, ZYJ (JHKs done)	

Target Notes:

1. We follow the observing strategy of the VIKING main survey: we split the observations into two OBs, with observations in 3 filters each. The reddest bands can be done in bright time. J band observations are split between the two OBs for added robustness of the photometric calibration.
2. The VIPERS observations do not cover the entire VIPERS area, but target two stripes which contain ten times as many galaxies with spectroscopic redshifts down to $i = 22.5$ as are available in VISTA fields thus far.
3. The VVDS fields provide about twice as many targets per unit area as VIPERS, with no photo-z preselection, and so are better suited to firming up the DIR calibration but will also be used in the CC calibration.
4. In P100, complete observations were taken for the first pointing of VIPERS-W1, and also the OBs covering VIPERS-W4 and VVDSF22 in JHKs were carried out.

12. Scheduling requirements

13. Instrument configuration

Period	Instrument	Run ID	Parameter	Value or list
102	VIRCAM	A	IMG	ZYJ
102	VIRCAM	B	IMG	JHKs

6b. Co-investigators:

...continued from Box 6a.

L.	Guzzo	1338
C.	Heymans	1649
C.	Morrison	2063
W.	Sutherland	1126
A.	Wright	1108