1 VISTA Deep Extragalactic Observations (VIDEO) Survey

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1.1 Abstract: (10 lines max)

The VISTA Deep Extragalactic Observations (VIDEO) survey is a 30 sq. degree, Z,Y,J,H,K_s survey that is specifically designed to enable exploration of the main issues in observational cosmology. It allows galaxy and cluster/structure evolution to be traced as a function of both epoch and environment from the present day out to z=4 and AGN/QSO evolution up to and into the epoch of reionization at $z > 6$. The multi-band nature of the survey ensures many key science drivers can be tackled using the survey alone, without recourse to data from other wavebands. The survey fields have been carefully selected to ensure a good RA spread and mix of fields with existing multi-band data thereby enhancing the usefulness of the survey to the whole of the astronomical community, and with an eye to future use of other ESO facilities such as ALMA which will require extragalactic targets at all RA. The area and depth means that VIDEO fits naturally between the proposed IR-KIDS and ultra-deep surveys, maximising the legacy to the ESO community.

2 Description of the survey: (Text: 3 pages, Figures: 2 pages)

2.1 Scientific rationale: The Aims of VIDEO

Large multi-wavelength surveys have already allowed us to make profound insights into the physics of galaxy formation and evolution and are providing us with our first hints of a complete theory of galaxy formation. However, they still suffer from two key drawbacks. First, they are usually based on optically-selected samples, making them insensitive to evolved galaxies at high redshifts as well as the most active, but heavily dust-obscured, systems at all redshifts. Thus they are relatively insensitive to both the earliest and final stages in the formation of galaxies – where the physics of galaxy formation may be most easily studied. Secondly, they typically cover only modest areas for studies at $z > 1$, typically ≤ 1 degree^2, corresponding to a transverse distance of $\lesssim$30 Mpc at $z \sim 2 - 4$. This scale is smaller than the largest structures, therefore these surveys are particularly sensitive to cosmic variance (e.g. Somerville et al. 2004) and thus provide only small and potentially biased samples of any strongly clustered or intrinsically rare objects (such as the most massive galaxies or very-high redshift AGN).

Moreover, detailed work on nearby spheroids (Thomas et al. 2005) has shown that those in the richest environments finish the bulk of their star formation earlier than those in the field. For the most massive galaxies this means $z > 2$, and studies of $z = 1$ clusters (e.g. Lidman et al. 2004; Rosati et al. 1999, 2002; Stanford et al. 2002, 2005; Mullis et al. 2005) all indicate that the more massive galaxies (those brighter than $L^\star$) all have colours indicative of stellar populations that formed at $z > 2$ and thereafter evolved passively. Work on the K-band luminosity function (and therefore mass function) of clusters (e.g. de Propris et al. 1999) agrees with this: the bright (high) end of the luminosity (mass) function is in place by $z = 1$ but the fainter (lower mass) end builds up over time to $z < 0.5$. It is likely that downsizing plays as important a role in clusters as it does in the field, albeit with star formation ending at an earlier time for a given galaxy mass. Thus, a clear view of the epoch before $z = 1$ is key to understanding how clusters built up their mass and how the galaxies within them evolved in response to the build-up of the clusters. During this epoch the more massive galaxies in a cluster must evolve, either in their star formation properties, or in their mass content, or potentially both.

We are already at a point where we have the best constraints ever on the spatial distribution and properties of galaxies in the local Universe from three of the largest surveys ever undertaken, namely the 2dF galaxy redshift survey (2dFGRS) and the Sloan Digital Sky Survey (SDSS) in the optical and the IRAS redshift survey selected in the far-infrared. With the VISTA Hemisphere survey this will be pushed out to $z \sim 0.6$, and IR-KIDS reaches $z \sim 1$ for an $L^\star$ galaxy. **The aim of the VIDEO survey is to gain a commensurate data set at $z < 4$ over a similar volume to the surveys covering lower redshifts. This will allow galaxy evolution to be traced over the majority of the Universe and from the richest clusters to the field populations.**

The VIDEO survey will be driven by the VISTA data alone, without the pre-requisite of additional data in other wavebands. However, the fields are chosen to incorporate current and future multi-wavelength data sets to facilitate the broadest exploitation of the VIDEO survey data both within ESO and across the globe.

1. Tracing the evolution of galaxies in all environments over 90% of the Universe's age

How and when were massive galaxies formed? When did they assemble the bulk of their stellar mass and how? Where does this mass assembly occur? These are crucial questions to which we still need answers.

The advent of deep multi-wavelength surveys has led to a huge progression in this field. Surveys in the optical wavebands have led the way for many years in surveying stellar light in the high-redshift Universe by utilising the Lyman-break technique (Steidel et al. 1996). More recently GALEX has stretched this to lower redshifts (e.g. Martin et al. 2005). However, these techniques are only sensitive to relatively unobscured systems, and are known to miss much of the luminosity density arising from galaxies at early epochs.

Surveys with the Spitzer satellite have led a revolution in extragalactic infrared astronomy; in particular SWIRE (Lonsdale et al. 2004) has enabled astronomers to trace the build-up of stellar mass in galaxies brighter than $L^\star$ from $z \sim 2$ to the present (e.g. Babbedge et al. 2006). Unfortunately, SWIRE does not have the depth to probe the formation and evolution of galaxies beyond this redshift except in rare cases where an AGN or massive starburst powers thermally-reprocessed dust emission.

Observations at near-infrared wavelengths are able to sample the stellar emission from young and old populations without being strongly affected by dust, and can thus supply a complete census of galaxy populations over the crucial epoch $1 < z < 4$. However, up until now surveys in the near-infrared have been limited to small area 'pencil beam' surveys (e.g. FIRES: Franx et al. 2003; GOODS: Caputi et al. 2006) and shallower ~ 1 sq.degree surveys (e.g. Drory et al. 2004). These surveys have led the way in probing galaxy evolution from the earliest times, but they are fundamentally limited by the fact that they cannot probe scales larger than a few Mpc, severely limiting investigations of the environmental dependence of galaxy formation and evolution. As recently shown, cosmic variance can be significant for even moderately large survey areas (e.g. the $0.8\,\mathrm{deg}^2$ of the CFHTLS; Ilbert et al. 2006) and the proposed VISTA ultradeep surveys.

This problem will be overcome with VIDEO, where the proposed depth allows $L^\star$ galaxies to be detected up to $z \sim 4$ (Fig. 1), while we can reach $0.1L^\star$ at $z \sim 1$, allowing us to constrain the apparent down-sizing in the mass function of forming galaxies. This will enable the bulk of the active epoch, where star-formation rate density and AGN activity were at a maximum (e.g. Madau et al. 1996; Steidel et al. 1999; Ueda et al. 2003; Richards et al. 2006) to be probed with galaxies emitting the bulk of the luminosity density. Crucially, VIDEO will also have sufficient area to make issues of cosmic variance negligible over all redshifts. Moreover, VIDEO will not only be able to detect the galaxies which contribute the bulk of the luminosity density at these redshifts, but its 5 near-infrared filters will produce photometric redshifts accurate to $\Delta z/(1 + z) < 0.2$ (see Fig. 1). This will provide the most advanced data set for studies over the whole of the epoch of activity.

It is already known that massive galaxies at all redshifts are strongly clustered, therefore the small areas that have been studied so far are subject to large cosmic variance. VIDEO will allow a robust measurement of the clustering of galaxies. The reduced sampling variance afforded by surveying a large volume means that trends in clustering strength with galaxy properties such as luminosity, colour (with the VIDEO data alone) and emission line strength (with spectroscopic follow-up) can be measured robustly. Such measurements will provide important new constraints on the models at high redshift (see Fig. 3). The clustering predictions tells us how the galaxy properties scale with the mass of the host dark matter halo, and thus reveal how the efficiency of different processes depends on the halo size.

2. Tracing the evolution of clusters from the formation epoch until the present day

VIDEO also provides data over the area and depth with which to study the evolution of galaxy clusters from their formation epoch to the present day. Galaxy clusters are essential tracers of cosmic evolution in the universe for two important reasons. First, clusters are the largest virialized objects whose masses we can measure. Mass measurements of local clusters can determine the amount of structure in the Universe on scales around 10^{14} $M_{\odot}$. Consequently, comparisons of the present-day cluster mass distribution with the distributions at earlier epochs can be used to determine the rate of structure formation, placing constraints on cosmological models (see Fig. 2). Second, the deep potential wells of clusters also mean that they act as closed astrophysical laboratories that retain their gaseous matter. Therefore clusters possess a wealth of information about the processes associated with galaxy formation such as the efficiency of which baryons are converted into stars and the effects which the resulting feedback processes have on galaxy formation.

At $0 < z < 1$, clusters of galaxies appear to undergo little in the way of strong evolution, either in their gas phase properties or in the properties of the more massive galaxies within them (e.g. Rosati et al. 2002). The epoch at $z > 1$ is therefore a crucial one for their evolution, which must be dramatic in the 4 Gyr between $1 < z < 4$. The design of VIDEO is such that it will be a crucial resource for the study of early cluster evolution. Its depth is such that it can trace the bright end of the cluster luminosity function to $z = 3$ and look in detail at the less luminous cluster galaxies to $z = 2$, while its area should provide a sample of several tens of clusters with masses above 10^{14} $M_{\odot}$. The actual number depends on the exact nature of cosmology and cluster evolution at $z > 1$ (see Fig. 2b), and therefore the measurement of this number with VIDEO will constrain these issues. Several of the fields chosen for VIDEO have (or will have) complementary multi-wavelength data that will allow the IR properties of the cluster galaxy population to be linked to the gas phase of the clusters, most notably in the XMM-LSS, ELAIS S1 and CDF-S fields whose excellent X-ray data are deep enough to identify the most massive clusters to $z > 1$. The VIDEO survey areas will also be within reach of the new Sunyaev–Zel'dovich telescopes (e.g. AMI, APEX, Bolocam, CBI, SPT and the SZ-array; see Carlstrom et al. 2002 for a review) which will be able to detect any virialized clusters down to a mass limit of $\sim 10^{14} M_{\odot}$, essentially independent of redshift. Therefore the SZ properties of VIDEO clusters in combination with spectroscopic velocity dispersions and X-ray properties can be used to investigate the interplay between feedback and cluster mass as a function of redshift.

3. Accretion activity within the epoch of reionization: the $z > 6$ QSO luminosity function

The SDSS has revolutionised studies of QSOs at the highest redshifts, and it provided the first evidence that the epoch of reionization was coming to an end around $z \gtrsim 6$. Pushing to higher redshifts is impossible with optical surveys, regardless of depth, due to the fact that the Gunn-Peterson trough occupies all optical bands at $z > 6.5$. Therefore, to push these studies further in redshift needs deep wide-field surveys in the near-infrared.

The VIDEO survey occupies a niche in the study of the highest redshift active galaxies. Up until now only the brightest QSOs at $z > 5$ have been found from the SDSS. In the future the UKIDSS Large Area Survey and wide-area VISTA public surveys will probe the bright end of the QSO luminosity function at $z > 6$. However, the *shape* of the QSO luminosity function at these redshifts can only be studied by much deeper near-infrared imaging over a significant survey area. This is the only direct way to determine the contribution of accreting black holes to the reionization of the Universe and constrain the density of black-holes within the first Gyr after the Big Bang.

The VISTA Z-band samples rest-frame wavelengths shortward of Lyα for objects with $z > 6.5$, so we can identify these objects using the standard dropout technique. However, cool dwarf stars are also very red in $Z - Y$ but can be differentiated from high-z QSOs by their $Y - J$ colours (Fig. 4a; Hewett et al. 2006). QSOs have $Z - Y > 1.5$ and $Y - J < 0.8$, and so we can make the distinction for objects brighter than our $Z = 25.2$ limit if we reach $Y = 23.7$ and $J = 23$. Extrapolating the QSO luminosity function of Fan et al. (2001) to $Y = 23.7$, we expect $z > 6.5$ QSOs to have a surface density of $\sim 1\,\mathrm{deg}^{-2}$ (Fig. 4b), and therefore there will be 30 QSOs within the epoch of reionization over the full VIDEO survey area. A more conservative estimate can be obtained by integrating down to a limit a full magnitude brighter than our survey depth, and this predicts a strong lower limit of 6 $z > 6.5$ QSOs within VIDEO.

VIDEO's combination of depth and area therefore provides the ideal way in which to probe the luminosity *function* of $z > 6.5$ QSOs. However, where optical data exist, the survey can find lower-redshift QSOs which are faint and/or reddened.

4. Legacy data for high-redshift supernovae

The host galaxies of supernovae hold important clues in form of their stellar populations. Their ages and metallicities are discriminants for alternative progenitor models. VIDEO will image the host galaxies of ~ 350 type-Ia SNe from the Supernova Legacy Survey (SNLS), mostly at $0.3 < z < 0.9$. Near-infrared data are critical for understanding the stellar populations of these galaxies, especially with respect to disentangling the effects of dust and age. We already have enough observational data to model the general galaxy populations at these (cosmologically low) redshifts as far as it is relevant for predicting SN host galaxy distributions given alternative SN models. These will then be compared against the real set of host galaxies from VIDEO on SNLS fields.

Moreover, it will be possible to obtain ZYJ magnitudes of a few SNLS supernova at the low end of the SNLS redshift range in real time (i.e. contemporaneously with the optical CFHT imaging and VLT/Gemini optical spectroscopy) which will provide a valuable extra constraint on the extinction of these events.

2.2 Immediate objective:

The principal aims of VIDEO is to provide a complete near-infrared data set of unprecedented depth and area from which many facets of galaxy formation and evolution can be explored. One of the main advantaged of VIDEO is that much of the science can be carried out with the VIDEO data alone due to the target redshifts and the 5-band filter approach. Thus, this truly will be a VISTA-led survey. Ancillary data sets from Spitzer, Herschel, along with X-ray and radio surveys will broaden the scientific impact of VIDEO across the ESO community and the world.

3 Are there ongoing or planned similar surveys? How will the proposed survey differ from those? (1 page max)

The only other survey which is currently underway or planned in the near future with similar aims is the UKIDSS-Deep Extragalactic Survey (DXS). The UKIDSS-DXS aims to survey $35\,\mathrm{deg}^2$ over four patches of sky to depths of $K \approx 21$ and $J \approx 23$. Obviously the DXS is similar to the survey which we are proposing here. However, there are crucial differences.

(i) The DXS will only observe to $K = 20.8$, roughly a magnitude brighter than VIDEO. In real terms this means that the current DXS only probes a passively evolving $L^\star$ galaxy to $z \sim 2$, whereas VIDEO extends this up to $z \sim 4$ and ensures complete coverage of the 'active epoch'. Probing a magnitude deeper also ensures that clusters of galaxies can be investigated in detail, both with the VIDEO data alone and also with follow-up observations. The usual method of detecting cluster galaxies from a single colour requires the survey to probe to $M^\star + 2$ at any given redshift. For DXS this mean galaxy clusters can be probed in full to $z \sim 0.8$, whereas with VIDEO this becomes $z \sim 1.5$ if just two filters are used.

(ii) UKIDSS-DXS only uses the J and K-bands over the full 35 square degrees. Therefore, we are only able to use the $J - K$ colour in order to decouple which galaxies are at $z > 1$. With the five near-infrared filters of

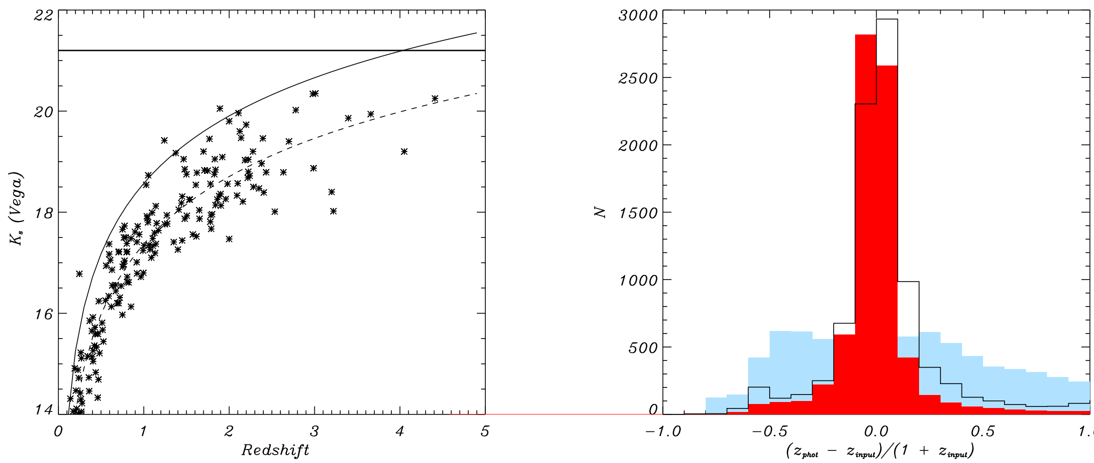

Figure 1: *(left)* K_s magnitude versus redshift for radio galaxies from Willott et al. (2003). The dashed line represents the K_s-band magnitude for a passively evolving $\sim 3\ L^\star$ galaxy, the solid curved line is the same for a 1 $L^\star$ galaxy. The thick solid horizontal line is the magnitude limit of the VIDEO survey, showing that we are able to detect an $L^\star$ galaxy up to $z \sim 4$. *(right)* Accuracy of photometric redshifts at $1 < z < 4$ with various filter combinations: VIDEO-ZJK (filled light blue/grey), VIDEO-ZYJHK$_s$ (solid line) and VIDEO-ZYJHK$_s$+IRAC (solid red/dark grey).

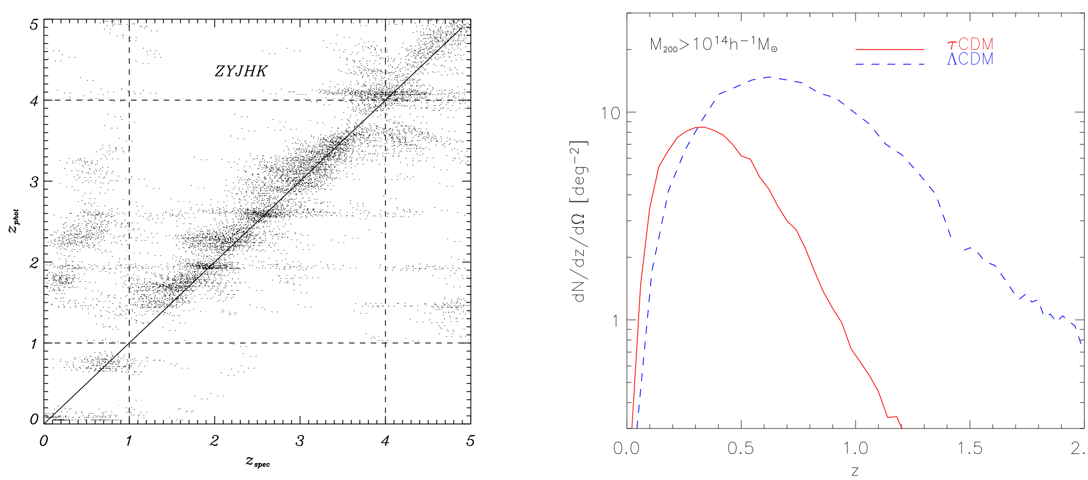

Figure 2: *(left)* The scatter in photo-zs for just the VIDEO ZYJHK$_s$ bands. One can see that galaxies between $1 < z < 4$ have reasonably accurate photometric redshifts with the VIDEO data alone. More sophisticated photo-z's with priors set my the galaxy luminosity function will also reduce the contaminants at $z < 1$ further. *(right)* The space density of clusters per unit redshift interval as a function of redshift, for the tCDM ($\Omega_{\rm M} = 1$) and LCDM ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.7$) cosmologies. Clusters are defined as dark matter haloes with $M_{200} > 10^{14}\ {\rm M}_\odot/h$. (Taken from the Virgo Consortium Hubble Volume simulations (Evrard et al. 2002).

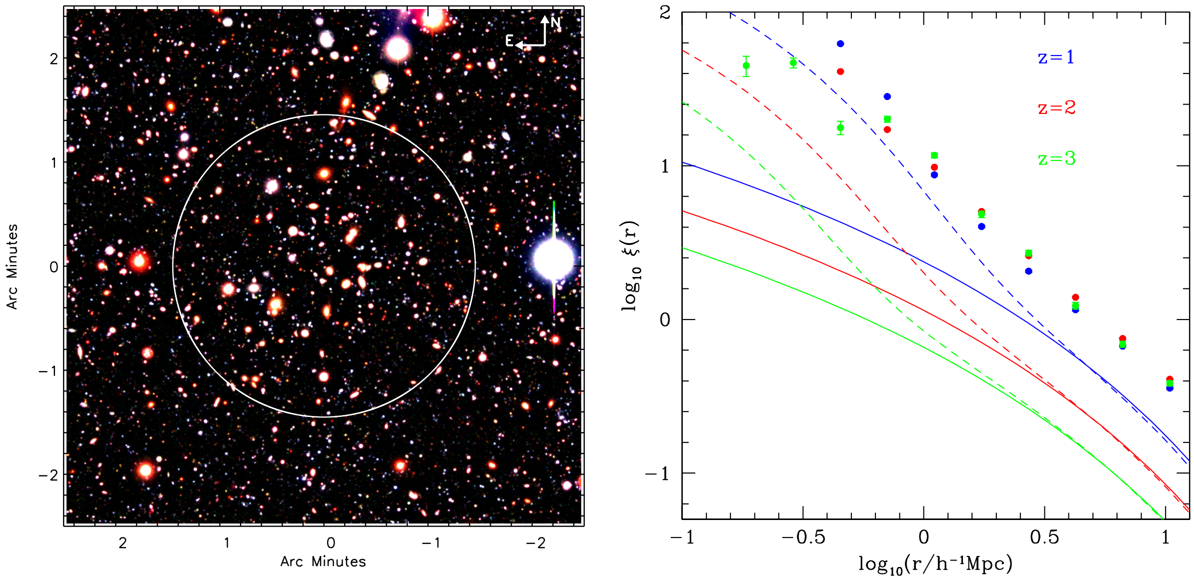

Figure 3: *(left)* A multi-colour image of a $z \sim 0.8$ galaxy cluster candidate from the UKIDSS-UDS early data release. *(right)* The lines show the correlation function of the dark matter in the Millennium Simulation (Springel et al. 2005). The solid lines show linear perturbation theory and the dashed lines show the non-linear correlation function. The points show the real space correlation function of galaxies with $K < 21.7$, extracted from the semi-analytical galaxy formation model of Baugh et al. (2005). The colours refer to $z = 3$ (green; bottom lines), $z = 2$ (red; middle lines) and $z = 1$ (blue; top lines).

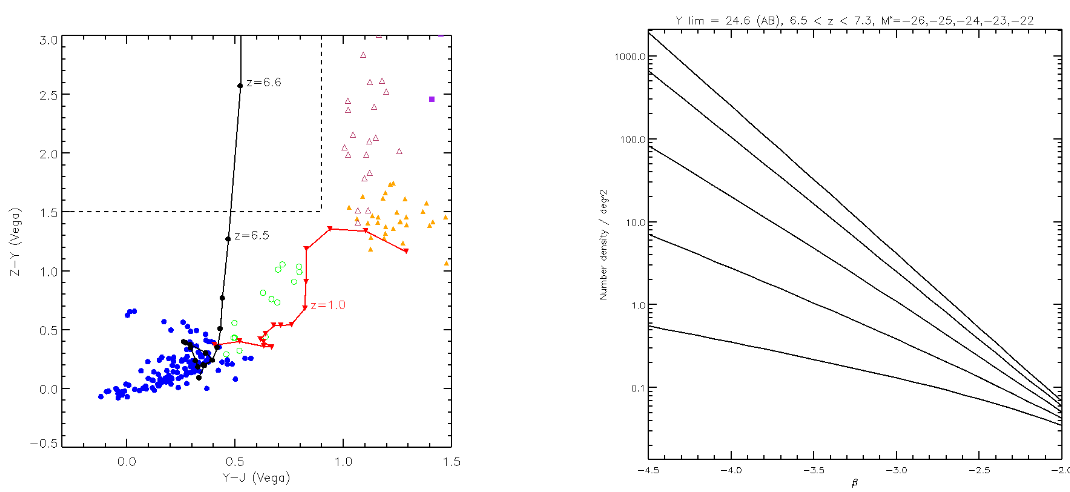

Figure 4: *(left)* Z-Y vs Y-J diagram illustrating colours of simulated stars, elliptical galaxies and quasars. The simulated objects colour coded as follows: BPGS O-K dwarfs (blue) filled circles; M dwarfs (green) open circles; L dwarfs (orange) filled triangles; T dwarfs (maroon) open triangles; Burrows model cool brown dwarfs (purple) filled squares; elliptical galaxies $0.0 < z < 1.5$, $\Delta z = 0.1$ red track with inverse triangles; quasars $5.0 < z < 6.7$, $\Delta z = 0.1$ black track with black circles with redshifts $z = 6.5$ and $z = 6.6$ marked. Quasar with redshifts $z > 6.5$ can be distinguished from cool stars by their red Z-Y colour and blue Y-J colour. The region in colour-colour space occupied by high redshift quasars is outlined by the dashed lines. *(right)* Number of quasars at $6.5 < z < 7.3$ expected per square degree within VIDEO with $Y < 24$(Vega) for various luminosity function parameters extrapolated from Fan et al. (2003). (The current limit on β is ~ 3.2 at $z > 6.5$ and $M^\star \sim -25$ at $z \sim 2$). The lines from top to bottom indicate the prediction using a luminosity function with $M^\star = -26, -25, -24, -23$ and -22. Therefore, we expect to be able to place the first measured constraints on the luminosity function at these redshifts.

VIDEO, much tighter photometric redshift constraints can be made, for instance using a simple template fitting approach, accuracies of $\Delta z/(1+z) < 0.2$ (see Figs 1b & 2a) can be obtained and adding priors can reduce this further. Thus, we will no longer have to rely on colour–magnitude relations to pick out candidate high-redshift clusters, as we will have a 3-dimensional view. The Oxford team is already applying these techniques to the UKIDSS-UDS Early Data release (which only covers $\lesssim$1 deg^2) with great success. Therefore, VIDEO is the only survey which has the depth and area and filter combination to find the rarest and most massive overdensities in the Universe from $z \sim 4$ to $z \sim 1$.

The VISTA IR-KIDS survey only has the depth to explore the Universe at $z < 1$ for an $L^\star$ galaxy. This is partly the reason why the optical data is crucial for KIDS as the characteristic galaxy spectral features still lie in the optical waveband. These characteristic spectral features are redshifted into the near-infrared bands at $z > 1$, and is what makes VIDEO the ideal project for studying this epoch.

VISTA Ultra-deep surveys have the depth to probe the Universe up to the highest redshifts, and will provide excellent data sets for the study of galaxy evolution since the epoch of reionization. However, what they gain in depth they lose in area, such that probing evolution as a function of environment with these surveys is severely hampered by cosmic variance. Again VIDEO will overcome this in the redshift range $1 < z < 4$.

4 Observing strategy: (1 page max)

Our strategy for observing the VIDEO fields is as follows. We will ensure, where possible, each full 1.6 sq.deg tile will be completed to the required VIDEO-specific depth in all five near-infrared colours once observations on a given tile have been started.

Tiles will be started from the centre of each field and working outwards to fill the whole survey field. This will ensure that there is always a VIDEO field available throughout the year over the five years of the survey.

The break down by Period would be as follows (see section 5.1 for full details of time justification).

Period	Time (h)	Mean RA	Moon	seeing	Transparency
P79(Apr'07-Sep'07)	123	18hr	Dark	< 0.8	THN,CLR
P79(Apr'07-Sep'07)	107	18hr	Grey	< 0.8	THN,CLR
P79(Apr'07-Sep'07)	62	18hr	Bright	< 0.8	THN,CLR
P79(Apr'07-Sep'07)	55	18hr	Bright	< 0.6	THN,CLR
P80(Oct'07-Mar'08)	123	06hr	Dark	< 0.8	THN,CLR
P80(Oct'07-Mar'08)	107	06hr	Grey	< 0.8	THN,CLR
P80(Oct'07-Mar'08)	62	06hr	Bright	< 0.8	THN,CLR
P80(Oct'07-Mar'08)	55	06hr	Bright	< 0.6	THN,CLR
P81(Apr'08-Sep'08)	123	18hr	Dark	< 0.8	THN,CLR
P81(Apr'08-Sep'08)	107	18hr	Grey	< 0.8	THN,CLR
P81(Apr'08-Sep'08)	62	18hr	Bright	< 0.8	THN,CLR
P81(Apr'08-Sep'08)	55	18hr	Bright	< 0.6	THN,CLR

The survey would continue with this strategy over the 5 years of the survey, resulting in a total of 385 nights.

5 Estimated observing time:

We base our exposure times on the typical elliptical galaxy colours at $z > 2$, where we are sensitive to the bulk of the luminosity density arising from galaxies. Therefore, for our limit of $K_S = 21.7$, this corresponds to $H = 22.7$, $J = 22.7$, and $Z = 25.2$. We also include observations in Y to enable us to perform high-redshift QSO – dwarf star separation. To distinguish these we require $Z - Y > 1.5$ and $Y - J < 0.8$, therefore we wish to probe to a depth of $Y = 24$.

Assuming 5σ for a point source in a 2 arcsec aperture, with 0.8 arcsec (0.6 arcsec in K_s) seeing we request the following (per source). † is the proposed UKIDSS-DXS depth in H over 5 square degrees.

Filter	Time (h) (per source)	Time (n) (per tile)	Time (n) (full survey)	5σ AB	$2''$ ap.mag. Vega	UKIDSS Vega	Seeing	Moon	Transparency
Z	21.9	7.3	136	25.7	25.2	–	0.8	D	THN,CLR
Y	7.7	2.6	48	24.6	24.0	–	0.8	G	THN,CLR
J	11.4	3.8	71	24.5	23.7	22.3	0.8	G	THN,CLR
H	11.1	3.7	69	24.0	22.7	$22^{\dagger}$	0.8	B	THN,CLR
K_s	9.9	3.3	61	23.5	21.7	20.8	0.6	B	THN,CLR

Four survey fields will be drawn from the following depending on time allocation to Ultra-Deep Survey fields and other scheduling considerations:

Field	RA-DEC	Total Area sq.degrees	Total Time nights
ELAIS-S1	0034-43	7	90
XMM-LSS	0218-05	9	116
CDF-S	0332-27	7	90
VIDEO-1	1400+05	7	90
VIDEO-2 (CFHTLS-D4)	2215-17	7	90
AstroF field	0444-53	7	90

The VIDEO-1 field is a new extragalactic field to fill the RA gap for extragalactic science with a view to ALMA and other upcoming instrumentation.

5.1 Time justification: (1 page max)

Our aim is to be able to detect a galaxy at the break of the elliptical galaxy luminosity function over 90% of the Universe, which corresponds to $0 < z < 4$. This ensures that we are sensitive to one of the most important epochs in the Universe, where star-formation and accretion activity were at a maximum.

We use the $K-$band luminosity function from 2MASS (Kochanek et al. 2001) where $M^{\star} = -24.3$. Assuming a passively evolving stellar population with a high formation redshift, in agreement with extremely red objects in the GOODS data set (e.g. Caputi et al. 2005), then we expect a $z \sim 4$ elliptical galaxy to have a total magnitude of $K = 21.2$. Under the assumption that 40% of a $z > 2$ elliptical galaxy's light is lost if a 2 arcsec aperture is used (see e.g. Jarvis et al. 2001) then the measured magnitude within this aperture would be $K \sim 21.7$, which defines our 5σ K_s-band limit.

For the K_s-band observations we use a tighter seeing constraint to enable accurate star-galaxy separation to be carried out over all of our fields in at least one filter, and the natural seeing is better in K_s than in the bluer filters.

We use the VISTA exposure time calculator to calculate all of our time requests. For the K_s band we use DIT=10 s with NDIT=6 s, and we use 2×2 microstepping to allow better Nyquist sampling for this seeing constraint, and a 5 point jitter pattern. To complete a half a tile (to ensure reasonable time per OB) with this strategy requires 1.3 hours (including overheads), which gives a 5σ point source sensitivity of $K_s = 20.4$ mag. This strategy therefore requires an extended time allocation per OB to ensure that most uniform coverage of a single 1.6 sq.degree tile, therefore we request a waiver for the K_s-band observations. To reach the full sensitivity over one tile therefore requires 12 exposure loops (29 hours), and to cover the full 30 sq.degrees requires 61 nights (9 hour nights).

For the $ZYJH$ bands we relax the seeing constrain to 0.8 arcsec as star-galaxy morphological separation will be carried out with the K_s-band observations. Therefore, we no longer require microstepping and use only a 5-point jitter pattern in each case.

For the H-band observations we again use a 5-point jitter pattern with DIT=10 s and NDIT=6. Therefore to complete a single 1.6 sq.deg tile requires 2360 s (including overheads). To reach the full tile depth of $H = 22.7$ (5σ, 2 arcsec aperture) requires 55 exposure loops (33.1 hours including overheads). For the full 30 sq.degrees this equates to 69 nights in total.

For the $J-$ we use 30 s DITs and NDIT=2, this equates to 2234 sec to complete one full 1.6 sq.deg tile down to a 5σ point source sensitivity of $J = 21.5$. Therefore to reach the full depth of $J = 23.7$ requires 55 exposure loops or 34.1 hours per 1.6 sq.degree tile. For the full 30 sq.degree survey area this equates to 71 nights (for 9 hours per night).

In Y we only aim to reach $Y = 24$ (Vega) to ensure that high-redshift quasar candidates can be distinguished from dwarf stars (Fig. 4a), whilst also providing extra photometric accuracy for Z-drop-out galaxies. This is relatively inexpensive and provides a large scientific benefit for $z < 2$ galaxies as well as the high-redshift quasar search. DIT=30 s and NDIT=2, with a 5-point jitter pattern means that to completely cover one tile requires 1800 s (2234 s including overheads) which reaches $Y = 22$ for a complete tile. Therefore to reach the full survey depth on a 1.6 sq.degree tile requires 40 exposure loops or 72000 s (22.8 hours including overheads). Thus to cover the full 30 sq.degree requires 48 nights.

In $Z-$band we use DIT=45 s and NDIT=1 with a 5-point jitter pattern. Covering a full tile twice (Exposure Loops=2) with this strategy requires 2700 (3314 s including overheads) per tile (including overheads) reaching a 5σ depth of $Z = 22.8$. To reach the full survey sensitivity of $Z = 25.2$ requires 150 exposure loops with this strategy taking 65 hours per tile. Therefore, the full 30 sq.degrees requires 136 nights.

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function	Affiliation	Country
M. Jarvis	PI & OB Preparation	Oxford	UK
A. Edge	OB Preparation	Durham	UK
R. McLure	OB Preparation	Edinburgh	UK
A. Verma	OB Preparation	MPE	D
CASU(VDFS)	Pipeline processing	Cambridge	UK
CASU(VDFS)	Data Quality Control-I	Cambridge	UK
J. Emerson	VDFS Coordinator	QMUL	UK
WFAU(VDFS)	Science Archive	Edinburgh	UK
WFAU(VDFS)	Data Quality Control-II	Edinburgh	UK
N. Walton	VO Standards	Cambridge	UK
	VIDEO Specific Tasks		
L. Clewley	Data Quality Control-III	Oxford	UK
I. Smail	Data Quality Control-III	Durham	UK
E. Bell, MPIA Postdoc	Data Quality Control-III	MPIA, Heid.	D
E. Gonzalez-Solares	Frame Stack	Cambridge	UK
Oxford Postdoc	Frame Stack	Oxford	UK
M. Jarvis, L. Clewley	Final Catalogue Production	Oxford	UK
I. Smail, K. Coppin	Final Catalogue Production	Durham	UK
K. Meisenheimer, Postdoc	Final Catalogue Production	MPIA, Heid.	D
J. Loveday	Final Catalogue Production	Sussex	UK
	Other data products		
O. Le Fevre	VIDEO-VIMOS strategy	OAMP	F
H. Röttgering	VIDEO-LOFAR strategy	Leiden	NL
S. Rawlings	VIDEO-GMRT cat. production	Oxford	UK
S. Oliver, I . Waddington	VIDEO-SWIRE cat. production	Sussex	UK
S. Oliver	VIDEO-Herschel strategy	Sussex	UK
S. Croom & R. Sharp	VIDEO-AAOmega cat. production	AAT	Other
M. Bremer & K. Romer	VIDEO-XMM cat. production	Bristol, Sussex	UK
G. Dalton	VIDEO-FMOS cat. production	Oxford	UK
F. Walter	VIDE0-(sub)mm-wave strategy	MPIA, Heid.	D
T. Readhead, M. Jones, K. Romer	VIDEO-SZ strategy	Caltech, Oxford, Sussex	USA,UK
M. Moles & M. Villar-Martin	VIDEO-EMIR strategy	IAA	Spain

The CASU (VDFS) team consists of Irwin, Lewis, Hodgkin, Evans, Bunclark, Gonzales-Solares, Riello. The WFAU (VDFS) team consists of Hambly, Bryant, Collins, Cross, Read, Sutorius, Williams.

6.2 Detailed responsibilities of the team:

We will use the VISTA Data Flow System (VDFS; Emerson et al. 2004, Irwin et al. 2004, Hambly et al. 2004) for all aspects of data management, including: pipeline processing and management; delivery of agreed data products to the ESO Science Archive; production of a purpose-built IVOA compliant science archive with advanced data-mining services; enhanced data products including federation of VISTA survey products with SDSS survey products. Standardised agreed data products produced by VDFS will be delivered to ESO, with a copy remaining at the point of origin (in the Science Archive in Edinburgh). 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 PPARC. The VDFS is a working systems-engineered system that is already being successfully employed for the UKIRT WFCAM surveys as a test bed 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.

The observation planning team will be led by the PI (Jarvis) and include members of the VIDEO teams from Edinburgh (McLure), Durham (Edge), MPIA-Heidelberg (Meisenheimer), MPE (Verma) and Sussex (Loveday & Oliver). They are responsible for generating the OBs using the Survey Area Definition Tool and P2PP and for revising these and monitoring survey progress using a local Data Quality Control database as necessary. Experience shows that the a full scientific validation is only possible when people start trying to do science with the data. Thus we will also have a number of people from Oxford, Durham, Edinburgh and MPIA carrying out the first checks on the pipeline-reduced data.

6.3 Data reduction plan:

The data reduction will be carried out using the VDFS, operated by the VDFS team, and augmented by Jarvis, Gonzales-Solares, Clewley, Smail and Bell, especially for product definition and product Quality Control.

6.3.1 Pipeline processing

The Cambridge Astronomy Survey Unit (CASU) are responsible for the VDFS pipeline processing component which has been designed for VISTA and scientifically verified by processing wide field mosaic imaging data from UKIRT's NIR mosaic camera WFCAM and is now routinely being used to process data from the WFCAM at a rate of up to 250GB/night. It has also been used to process ESO ISAAC data e.g. the FIRES survey data and a range of CCD mosaic cameras.

The pipeline includes the following processing steps but is a modular design so that extra steps are easily added. All the steps will have been tested on a range of input VISTA datasets. and include: instrumental signature removal – bias, non-linearity, dark, flat, fringe, cross-talk; sky background tracking and removal during image stacking – possible need to also remove other 2D background variations from imperfect multi-sector operation of detectors; define and produce a strategy for dealing with image persistence from preceding exposures; combine frames if part of an observed dither sequence or tile pattern; consistent internal photometric calibration to put observations on an approximately uniform system; basic catalogue generation including astrometric, photometric, shape and Data Quality Control (DQC) information; final astrometric calibration from the catalogue with an appropriate and World Coordinate System (WCS) in all FITS headers; basic photometric calibration from catalogue using suitable pre-selected standard areas covering entire field-of-view to monitor and control systematics; each frame and catalogue supplied with provisional calibration information and overall morphological classification embedded in FITS files; propagation of error arrays and use of confidence maps; realistic errors on selected derived parameters; nightly extinction measurements in relevant passbands; pipeline software version control – version used recorded in FITS header; processing history including calibration files recorded in FITS header

6.3.2 Science archiving

The concept of the science archive (SA, Hambly et al. 2004 and references therein) is key to the successful exploitation of wide field imaging survey datasets. The SA ingests the products of pipeline processing (instrumentally corrected images, derived source catalogues, and all associated metadata) into a database and then goes on to curate them to produce enhanced database-driven products. In the VDFS science archive, the curation process includes, but is not limited to, the following: individual passband frame association; source association to provide multi-colour, multi-epoch source lists; global photometric calibration; enhanced astrometry including derivation of stellar proper motions; consistent list-driven photometry across sets of frames in the same area; cross-association with external catalogues; and generation of new image products, e.g. stacks, mosaics and difference images etc., all according to prescriptions set up for a given survey programme. All these features are available in the context of a continually updating survey dataset from which periodic releases (as required by the community) can be made.

Moreover, end-user interfaces were catered for from the beginning in the VDFS design process, and the philosophy has always been to provide both simple and sophisticated interfaces for the data. The former is achieved via simple point-and-click web forms, while the latter is achieved via exposing the full power of the DBMS back-end to the user. To that end, full access to Structure Query Language and the relational organisation of all data are given to the user.

We have developed a generalised relational model for survey catalogue data in the VDFS. The key features to note are the normalised design with merged multi-waveband catalogue data (the table of most use for scientific queries) being part of a related set of tables that allow the user to track right back to the individual source images if they require to do so; and also that the merged source tables (as derived either from individually analysed images, or consistently across the full passband set available in any one field) are seamless, and present the user with a generally applicable science-ready dataset. Similar relational models describe the organisation of all data in the science archive (image, catalogue, calibration metadata, etc.) - see Hambly et al. (2004) and references therein. The relational model is applicable to any imaging survey project, and provides an easy-to-use science-ready data resource for the community scientist in the form of a seamless, merged multi-colour multi-epoch source catalogue. The science archive has a high-speed query interface, links to analysis tools such as TopCat, and advanced new VO services such as MySpace.

Data products are being successfully ingested into the WFCAM Science Archive (WSA) in Edinburgh, with the EDR in Feb 2006, and the WSA concept was also demonstrated on the SuperCOSMOS Science Archive (SSA). *http://surveys.roe.ac.uk/ssa/.*

6.4 Expected data products:

Instrumentally corrected frames (pawprints, tiles etc) along with header descriptors propagated from the instrument and processing steps (science frames and calibration frames)
Statistical confidence maps for each frame
Stacked data for dithered observations
Derived catalogues (source detections from science frames with standard isophotal parameters, model profile fitted parameters, image classification, etc.)
Data Quality Control database
Database-driven image products (stacks, mosaics, difference images, image cut-outs)
Frame associations yielding a survey field system; seamless, merged, multi-colour, multi-epoch source catalogues with global photometric calibration, proper motions (where appropriate)
Source re-measurement parameters from consistent list-driven photometry across all available bands in any one field **The multi-wavelength stacked catalogues will also be made available by the VIDEO team led my Jarvis and the specific task leaders highlight in table 6.1.**

6.5 General schedule of the project:

T0: Start of observations
T0+8months; Release of science products from first month of survey observations
T0+14month; Release of science products from first 6 months of survey observations
Thereafter we would hope that science products can be released within 6 months of raw data arriving in the UK. Optional reprocessing of data based on improved knowledge of instrument would also be considered

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7 Envisaged follow-up: (1 page max)

Spectroscopic and small-area deep imaging follow-up

Possibly one of the most important steps for these follow-up studies is the acquisition of redshift information. One of the main aims of VIDEO is to probe galaxies and clusters in the traditional 'redshift desert' at $1.3 < z < 1.7$, i.e. where there are no bright emission lines in the optical waveband. Therefore, it is both crucial and timely that multi-object near-infrared spectrographs are becoming available on the largest telescopes. In particular FMOS on Subaru and EMIR on the GTC in the northern hemisphere and KMOS on the VLT in the southern hemisphere. Moreover, to probe candidate distant clusters, where only a few objects appear to be grouped in the VIDEO survey, will require deeper smaller area follow-up observations. HAWK-I will be the ideal instrument to probe further down the cluster luminosity function of putative $z \sim 2$ cluster candidates. This is in addition to the instruments currently available on the VLTs and other facilities. For instance VIMOS will continue to be the premier instrument for multi-object spectroscopy in the optical regime.

From Spitzer to Herschel

The ELAIS-S1, CDF-S and XMM-LSS fields form part of the Spitzer Wide-area InfraRed Extragalctic legacy survey, (SWIRE, Lonsdale et al. 2003, 2004). The SWIRE survey is now complete (final public data release July 2006) and covers a total of 49 sq. deg in six fields. These fields were carefully chosen to be in regions of low galactic dust column density and on this figure of merit they are some of the best fields on the sky. We also know of a number of further Spitzer proposals to observe these fields including one proposal to observe the full SWIRE CDF-S region (8 sq. deg) from $24 - 160$ μm with a factor of 10 times the current integration. In the current plans the three southern SWIRE fields will also be covered in Herschel guaranteed time to a depth of 60mJy at 250, 350 and 500 micron, these observations will pick out some of the most extreme obscured objects perfect for study with VISTA and ALMA. In addition one field, probably CDFS or XMM-LSS will be completely covered to a much greater depth. The data will have a limited proprietary period and the project teams will be obliged to produce usable data products. The period will be 1 year for observations in the first year and six months after that.

(Sub)-millimetre follow-up

(Sub)millimetre observations of key targets detected by VIDEO will constrain the dust and molecular gas content in objects in the very early universe. Observations using (sub)millimetre bolometers (JCMT/SCUBA2, APEX/LABOCA and IRAM/MAMBO), in addition to the Spitzer/Herschel observations, are critical to constrain the total FIR luminosities of high-redshift sources. It is of particular importance to derive the properties of the molecular gas, from which stars form, in systems in the very early universe (i.e. gas mass, dynamics and excitation). All the fields targeted by VIDEO will also be reachable with ALMA, making sensitive and high resolution follow-up CO observations feasible, e.g. for the highest-redshift ($z > 6$) QSOs observations of the molecular gas phase provide invaluable clues regarding the masses of the host galaxies as well as the reservoir of gas that may ultimately form stars. These observations are also of fundamental importance in deriving the dynamical masses of these objects and thus help to put limits on deviations of the M-σ relation as a function of z and constrain ΛCDM models/simulations in the early stages of galaxy assembly.

Galaxy clusters in the X-ray and the SZ effect

As discussed in section 2.1, there is a clear synergy between VIDEO and X-ray/SZE cluster surveys. Our survey regions have been chosen to leverage existing X-ray cluster surveys, e.g. XMM-LSS, and also to allow sufficient RA and Dec coverage to be accessible by the upcoming SZE optimised instruments. The existence of VIDEO data will precipitate requests by this team, and the rest of the X-ray community, for new X-ray surveys in those regions not already well covered by XMM or Chandra. Looking to the future, VIDEO will produce exactly the sort of high redshift clusters, AGN and quasars that will be needed as targets for the next generation of X-ray satellites (e.g. XEUS, Con-X). The SZE is a particularly powerful method to discover high redshift clusters, but it requires exhaustive optical/SZ follow-up to secure identifications and redshifts. It is only natural that SZE teams will want to survey the VIDEO regions, in order to get such follow-up "for free". VIDEO plus SZE will be a uniquely powerful method to select clusters at the very epoch of formation.

8 Other remarks, if any: (1 page max)

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