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 15 sq. degree, Z,Y,J,H,K_s survey specifically designed to enable 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 and the most massive galaxies up to and into the epoch of reionization. With its depth and area, VIDEO will be able to fully probe the *epoch of activity* in the Universe, where AGN and starburst activity were at their peak and the first galaxy clusters were beginning to virialise. VIDEO therefore offers a unique data set with which to investigate the interplay between AGN, starbursts and environment, and the role of *feedback* at a time when it is most crucial. 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. However, 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 APEX and ALMA. The area and depth means that VIDEO fits naturally between the proposed VIKING and Ultra-VISTA surveys, maximising the legacy to the ESO community and worldwide.

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

2.1 Scientific rationale: The Aims of VIDEO

We are already at a point where we have excellent constraints 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; Colless et al. 2001) and the Sloan Digital Sky Survey (SDSS; Adelman-McCarthy et al. 2006) in the optical and the IRAS redshift survey (Saunder et al. 2000) selected in the far-infrared. With the VISTA Hemisphere survey this will be pushed out to $z \sim 0.6$, and the VISTA-VIKING survey will reach $z \sim 1$ for an $L^\star$ galaxy. **The aim of the VIDEO survey is to gain a commensurate data set at $1 < z < 4$ 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.**

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. The main scientific aims of VIDEO are described below.

2.1.1 Tracing the evolution of galaxies in all environments over 90% of the Universe

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.

(i) Galaxy formation over the epoch of activity

The advent of deep multi-wavelength surveys has led to a huge progression in this field. There are two ways to measure the build-up of stellar mass: by directly observing star formation, or by measuring the total stellar mass already formed by a given epoch. The first technique was revolutionised by the Lyman break technique (Steidel et al. 1996) which found large numbers of star forming galaxies at $z \sim 3$. 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.

On the other hand, mass estimates of distant galaxies require long-wavelength observations to probe rest-frame wavelengths which are not dominated by young stars with low mass-to-light ratios. Surveys with Spitzer, and in particular the 49 sq.deg. covered by SWIRE (Lonsdale et al. 2004) have allowed substantial recent progress in this area (e.g. Babbedge et al. 2006). However, not even Spitzer has the combination of being able to reach both to deep limits *and* wide areas as it is a small telescope with a relatively small field-of-view. This is borne out by the fact that SWIRE only reaches $z \sim 2$ for an $L^\star$ galaxy. Surveys such as GOODS do probe to much greater depths but only cover very small sky areas. This has also been the problem with previous ground-based surveys like FIRES (Franx et al. 2003). Up until now, these surveys have led the way in probing galaxy evolution from the earliest times up until the present day, 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). But VISTA is ushering in a new era of cosmology by enabling us to rapidly survey representative volumes of the high-redshift Universe.

This is the goal of VIDEO, which will perform an in-depth study of the Universe during the crucial era $1 < z < 4$, linking the shallower surveys (like VHS and VIKING) with the Ultra-VISTA survey. The depths of the VIDEO survey have been carefully chosen to reach $L^\star$ at $z = 4$, and $0.1\ L^\star$ at $z = 1$, thereby enabling us to detect the bulk of the luminosity density arising from galaxies over 90% of the Universe and the most massive galaxies at the highest redshifts. Thus we will be able to investigate in exquisite detail which galaxies are in place first, and address the issue of downsizing in the mass function of forming galaxies where the massive early type galaxies appear to be in place before the less massive galaxies (e.g. Cimatti, Daddi & Renzini 2006). It is also important to note that the epoch over which VIDEO is aimed is a crucial one in the history of the Universe, as this is when the bulk of the star-formation and accretion activity took place (e.g. Madau et al. 1996; Steidel et al. 1999; Ueda et al. 2003; Richards et al. 2006) and so is the ideal survey with which to investigate the effects that star-formation and accretion activity have on galaxy evolution in general. Moreover, the intrinsic rarity of the most luminous AGN, starburst and elliptical galaxies means that it is important to survey a large enough area from which the luminosity function and clustering of particular objects can be constrained, thus enabling the evolution of bias to be determined. Crucially, VIDEO will have sufficient area to carry out these investigations as a function of both redshift and environment. The area of VIDEO ensures that we are able to explore $\sim 2 \times 10^7\ h^{-3}\ \mathrm{Mpc}^3$ at $z < 1$, where we are sensitive to galaxies with $L < 0.1\ L^\star$. Fig. 3 shows that with this survey we will detect ~ 200 haloes with $M > 10^{14}\ \mathrm{M}_\odot$ at $z < 1$ (see also Fig. 4) and ~ 2 haloes with $M > 10^{15}\ \mathrm{M}_\odot$, and as described in section 2.2 a significant sample of massive dark matter haloes at much higher redshifts. Thus, VIDEO will be able to explore the progenitors of all environments we see in the Universe today.

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 $\Delta z/(1+z) \sim 0.15$ (see Fig. 1), and to a higher degree of accuracy with ancillary optical data (see section 7). This will provide the most advanced data set for studies over the whole of the epoch of activity.

(ii) Statistical studies of the most massive galaxies at the highest redshifts

In addition to probing the sub-$L^{\star}$ population up to $z \sim 4$, VIDEO will be uniquely placed to quantify the density and spatial clustering of the most massive galaxies at the earliest epochs. Recent work with the UKIDSS-UDS Early Data Release show that the space density of $z \sim 5$ galaxies with stellar mass $M > 10^{11}$ $M_{\odot}$ (McLure et al. 2006) is ~ 18 per square degree (Fig. 2). This study was carried out with data ~ 1 mag brighter than the proposed limit of VIDEO and over 30-times less area. Using the results of this study, means that we expect ~ 270 $M > 10^{11}$ $M_{\odot}$ galaxies at $z \sim 5$ due to the increase in area, and extrapolating in redshift according to Press-Schechter (Bond et al. 1991) we expect ~ 140 $M > 10^{11}$ $M_{\odot}$ galaxies at $z \sim 6$ due to the increase in both area and depth (Fig. 2). Thus we will be able carry out the first statistically significant clustering analysis towards the epoch of reionisation, providing a direct link between the underlying dark matter distribution and galaxy populations and how this evolves up to the highest redshifts. We note that the Ultra-VISTA survey will detect ~ 10 times fewer $M > 10^{11}M_{\odot}$ galaxies at this important epoch, as the limiting factor is area rather than depth, thus making clustering analyses impossible. However, we emphasise that the combination of VIDEO and Ultra-VISTA will provide the premier data set for investigating the clustering properties of the highest redshift ($z > 4$) galaxies as a function of mass.

2.1.1 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. 4). 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 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} $M_{\odot}$ at $z > 1$. Our recent study over ~ 0.5 sq.degree (van Breukelen et al. 2006; Fig. 5) in the SXDF with UKIDSS-Ultra-deep survey and Spitzer-SWIRE data has shown that there are ~ 5 $M > 10^{14}$ $M_{\odot}$ clusters per square degree at $z > 1$, consistent with ΛCDM cosmologies (Fig. 4). However, this study is severely limited by sample variance. Therefore larger areas are required in order to pin down the evolution of galaxies within clusters *and* the evolution in the cluster mass density at $z > 1$. With VIDEO we expect to discover ~ 75 massive clusters at $z > 1$ with the bulk of these ($\sim 80\%$) at $1 < z < 1.5$ (Fig. 4). Moreover, the depth of VIDEO coupled with the 15 sq.deg area ensures that we will also have a statistically meaningful sample of massive galaxy clusters at $z > 1.5$. In ΛCDM cosmologies we expect ~ 1 $M > 10^{14}$ $M_{\odot}$ clusters per sq.deg at $z > 1.5$, thus in VIDEO we expect ~ 15 massive clusters at a time when they are just beginning to virialise.

Several of the fields chosen for VIDEO have (or will have) complementary multi-wavelength data that will allow the infrared properties of the cluster galaxy population (from VIDEO and SWIRE) 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, CBI2, 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, thus perfectly complementary to VIDEO. Using cluster surveys to trace the evolution of Dark Energy in the Universe has the potential to exceed the expectations of Baryon Acoustic Oscillation and Supernovae techniques, but they also have the largest systematic errors (see report of the Dark Energy Task Force; Albrecht et al. 2006). To overcome these systematic errors we need to understand the astrophysics of cluster evolution, and thus VIDEO data will be crucial in combination with X-ray and SZ surveys, along with spectroscopic follow-up.

2.1.3 Accretion activity over the history of the Universe

(i) The first accreting black holes

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 $z \gtrsim 6$ (Becker et al. 2001). 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. **VIDEO's combination of depth and area provides the ideal way in which to place the first constraints on the luminosity *function* of $z > 6.5$ QSOs.**

Up until now only the brightest QSOs at $z > 5$ have been found using the SDSS. In the future the UKIDSS Large Area Survey and wide-area VISTA public surveys such as VIKING and the VISTA hemisphere survey 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 with 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, as just using the brightest quasars requires a huge extrapolation to fainter magnitudes.

The VISTA Z-band samples rest-frame wavelengths blueward 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. 6; 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. 7), thus there will be ~ 15 QSOs within the epoch of reionization over the full VIDEO survey area.

(ii) The peak of accretion activity in the Universe

Where optical data exist, VIDEO can find lower-redshift QSOs which are faint and/or reddened. However, more interesting constraints could be made on the obscured AGN population when the VIDEO survey data is combined with Spitzer-SWIRE, X-ray and Herschel observations. The depth of VIDEO is crucial in determining the nature of distant obscured AGN. Although the central quasar is obscured in these objects, VIDEO will have the sensitivity to detect the host galaxies of such sources up to ~ 5 assuming that their host galaxies are $\sim 2 - 3\ L^{\star}$. However, these sources are rare. Given current work over the ~ 4 sq.deg of the Spitzer First Look Survey (Martinez-Sansigre et al. 2005; 2006; Bonfield et al. in prep.) we expect ~ 300 heavily obscured quasars at $z > 2$ in VIDEO. Therefore, VIDEO could in essence probe the cosmic evolution of all AGN, both obscured and unobscured. Such a statistical study is beyond the reach of Ultra-VISTA due to the small area (expect ~ 30), and VIKING due to its relatively shallow depth, as well as the UKIDSS-DXS due to having only 2 filters and ~ 1 mag brighter sensitivity. These intrinsically rare, but important objects, will be prime targets for ALMA as their CO masses will be large and hence dynamical masses could be measured over the history of the Universe.

To summarise, VIDEO data, coupled with Spitzer-SWIRE, X-ray, and in the future, Herschel data, will go along way to providing a full census of AGN activity over the epoch when these sources were accreting at their maximum level. With the large area covered such activity can also be probed as a function of environment, a problem which can only be addressed with the depth *and* area of VIDEO.

2.1.4 The VIDEO supernovae project

The VIDEO survey also provides an opportunity for a large-volume supernova (SN) search in a random volume of the low-redshift universe. In particular, near-infrared observations can be used select SNe almost independently of dust obscuration in their host galaxies. It will thus facilitate the best rate assessments for different SN types and their dependence on host galaxy properties (e.g. mass, star-formation rate, metallicity). The VIDEO-SNe team led by C. Wolf and including several members of the former EU RTN on SN progenitors, including

Patat & Leibundgut at ESO, has developed a strategy for the SN search. With VIDEO, 250 core-collapse and 100 type-Ia SNe are expected during the 5-year project, at a median redshift of 0.2 in the ZYJ-bands. Host galaxies will also be studied spectroscopically to constrain metallicities and unobscured star-formation rate. The multi-wavelength data, such as Spitzer and Herschel will also be used to assess star formation rates and stellar masses. This will allow us to check the consistency of SN-rate and star-formation rates and assess possible metallicity-dependencies in SN rates of all types. The inclusion of dust-obscured SNe in a full sample will probably not increase the cosmic SN rates very much, but it will remove an important bias that is strongly correlated with host galaxy properties. *Possibilities of VISTA data being pipeline-reduced on Paranal to search for transients are currently being explored with ESO.*

2.2 Immediate objective:

The principal aim of VIDEO is to provide a complete near-infrared data set of unprecedented depth and area from which galaxy formation and evolution as a function of both epoch and environment can be explored. One of the main advantages 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. This truly will be a VISTA-led survey. Ancillary data sets from Spitzer, Herschel, along with optical, X-ray, radio and SZ surveys will broaden the scientific impact of VIDEO across the ESO community and the world. We emphasise that the surveys carried out at these other wavelengths are uniquely matched to the area of VIDEO. The 1000 sq.deg. of VIKING will never have matching data in these wavebands. Furthermore, the Ultra-VISTA survey will be limited by sample variance for the rarest and most massive structures, these are exactly the structures which will preferentially be detected with X-ray and SZ surveys. VIDEO is therefore crucial for these studies.

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 $K \approx 20.8$ and $J \approx 23$. Three of the four DXS fields cover SWIRE areas, and only one of these (XMM-LSS) is visible to ESO telescopes. The XMM-LSS field also contains the UKIDSS-Ultra Deep Survey field, thus it is likely that VIDEO will complete the larger XMM-LSS area on a shorter timescale than UKIDSS-DXS will, leaving the DXS to concentrate on the northern SWIRE fields.

VIDEO also has other crucial differences to UKIDSS-DXS:

(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 means galaxy clusters can be probed in detail to $z \sim 0.8$, whereas with VIDEO this becomes $z \sim 1.5$, where we expect the most massive clusters to begin to virialise.

(ii) UKIDSS-DXS only uses the J and K-bands over the full 35 square degrees. Therefore, with the DXS 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 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 1 & 2) can be obtained and adding optical and SWIRE data can reduce this to $\Delta z/(1 + z) \sim 0.1$ over $0 < z < 5$. 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 has already applied these techniques to the UKIDSS-UDS Early Data release (which only covers $\lesssim 1\,\mathrm{deg}^2$) with great success (van Breukelen et al. 2006). VIDEO is the only survey which has the depth, area and filter combination to find the rarest and most massive overdensities in the Universe from $z \sim 4$

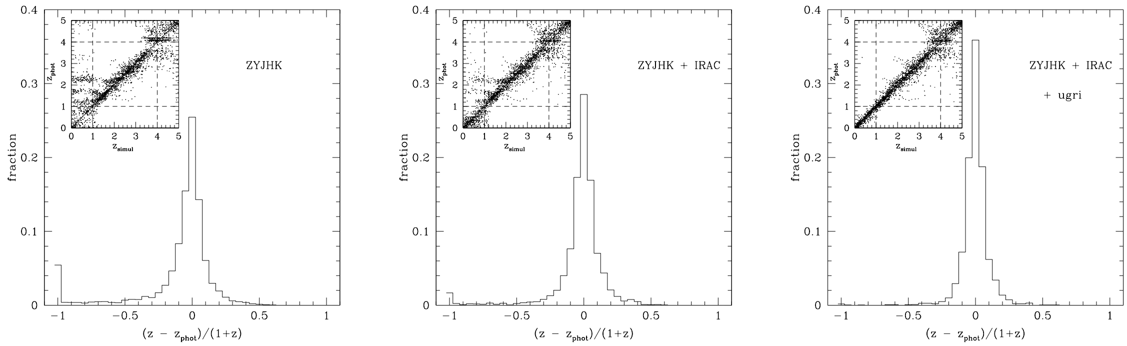
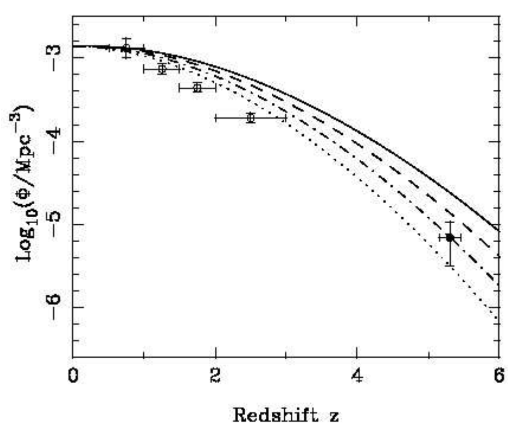


Fig. 1a *(left)* Accuracy of photometric redshifts with VIDEO-ZYJHK alone. One can see that the photometric redshifts are well constrained over the full range in redshift that VIDEO aims to explore $1 < z < 4$ even without optical or Spitzer data with $\sigma = 0.15$. **Fig. 1b** *(middle)* Accuracy of photometric redshifts with VIDEO-ZYJHK + SWIRE-IRAC data. One can see that the photometric redshifts are well constrained over the full range in redshift ($0 < z < 5$) even without optical data, with a $\sigma = 0.25$. **Fig. 1c** *(right)* The photometric redshift distribution for VIDEO-ZYJHK + SWIRE-IRAC + ugri optical imaging with AB magnitude=25 in each optical band. One can see that the addition of this relatively shallow optical data set reduces the uncertainties at $z < 1$ dramatically ($\sigma = 0.11$ for $0 < z < 5$). We note that deeper data than this already exists over CDF-S and similar depth data exists over XMM-LSS. We note that for the redshift range $1 < z < 4$ the photometric redshift uncertainties using all bands are consistent with the photometric redshifts using the VIDEO data alone, i.e. $\sigma \sim 0.15$.



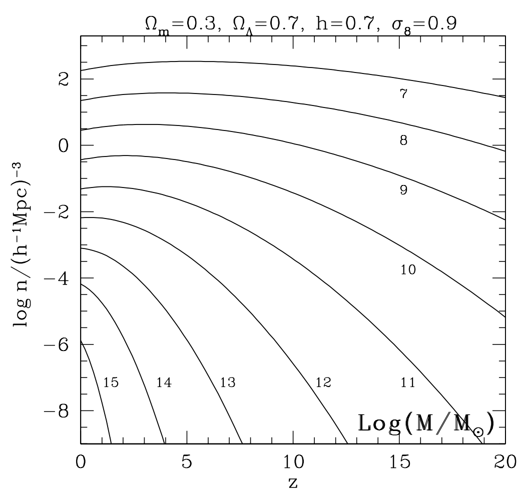
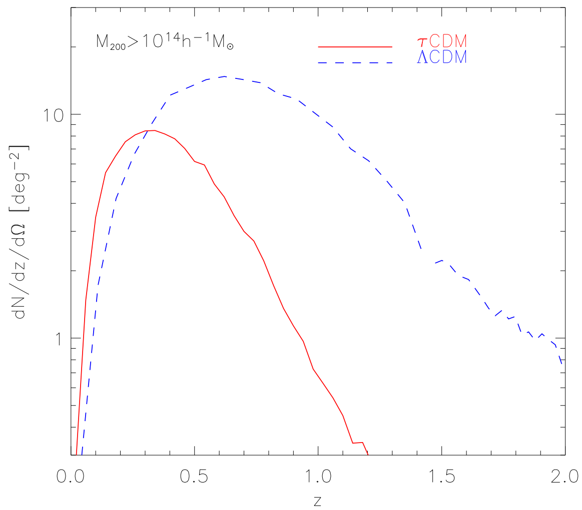


Fig. 2 *(left)* The filled circle at $z = 5.3$ is the estimate for the number density of galaxies with stellar masses greater than $\simeq 10^{11}\,\mathrm{M}_\odot$ from the study of McLure et al. (2006). The data-points at $z \leq 3$ (open circles) are the estimated number densities of galaxies with stellar masses $\mathrm{M} \geq 10^{11}\,\mathrm{M}_\odot$ from the GOODS CDFS $K-$band selected sample of Caputi et al. (2006). The curves show the redshift evolution of the number density of dark matter halos with masses $\mathrm{M} \geq 1.5 \times 10^{12}\,\mathrm{M}_\odot$. The solid, dashed, dot-dash and dotted curves correspond to four different values of σ_8 (0.90, 0.85, 0.80 & 0.75 respectively) **Fig. 3** *(right)*. Each curve indicates the variation with redshift of the comoving number density of dark matter haloes with masses exceeding a specific value M in the standard ΛCDM model with $\Omega_\mathrm{M} = 0.3$, $\Omega_\Lambda = 0.7$, $h = 0.7$ and $\sigma_8 = 0.9$. The label on each curve indicates the corresponding value of $\log(M/\mathrm{M}_\odot)$ [Taken from Mo & White (2002)].



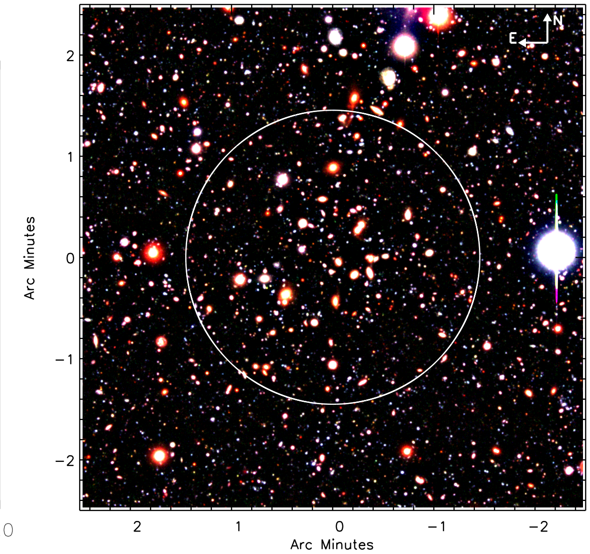
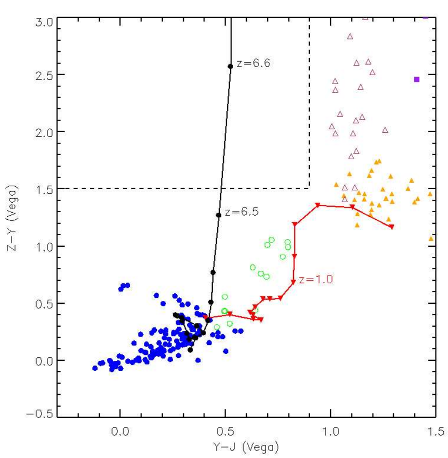


Fig. 4 *(left)* The space density of clusters per unit redshift interval as a function of redshift, for the τCDM ($\Omega_{\rm M} = 1$) and ΛCDM ($\Omega_{\rm M} = 0.3$, $\Omega_\Lambda = 0.7$) cosmologies. Clusters are defined as dark matter haloes with $M_{200} > 10^{14}\ {\rm M}_\odot/h$. (Taken from the Virgo Consortium Hubble Volume simulations (Evrard et al. 2002). **Fig. 5** *(right)* A multi-colour image of a $z \sim 0.8$ galaxy cluster from the UKIDSS-UDS early data release combined with deep optical data from Subaru (van Breukelen et al. 2006). We note that VIDEO will be able to take this sort of study out to $z \sim 2$.



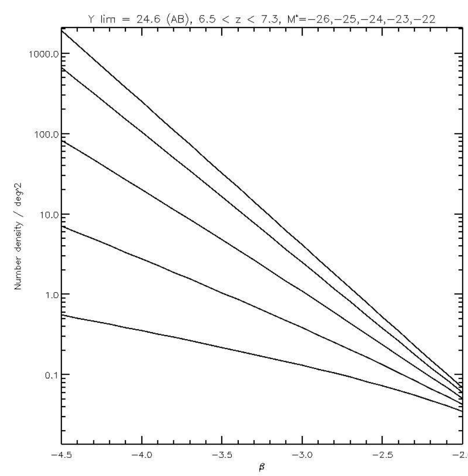


Fig. 6 *(left)* Z-Y vs Y-J diagram illustrating colours of simulated stars, elliptical galaxies and quasars. The simulated objects colour coded as follows: BPGS O-K dwarfs (blue) filled circles; M dwarfs (green) open circles; L dwarfs (orange) filled triangles; T dwarfs (maroon) open triangles; Burrows 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. **Fig. 7** *(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.

to $z \sim 1$.

The VISTA-VIKING 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. Moreover, by surveying areas covered by Spitzer SWIRE we will have 9-band photometry tuned to obtain photometric redshifts at $z > 1$, similarly to KIDS+VIKING at $z < 1$. Additional moderate depth optical data from the VST would increase photometric redshift accuracy of the whole survey further by reducing the amount of low-redshift contaminants to the $z > 1$ populations. We note that many of our fields already have adequate optical waveband coverage from other surveys (e.g. CFHT-Wide, CTIO and VVDS).

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 (see Scientific Rationale).

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)	57	18hr	Dark	< 0.8	THN,CLR
P79(Apr'07-Sep'07)	48	18hr	Grey	< 0.8	THN,CLR
P79(Apr'07-Sep'07)	28	18hr	Bright	< 0.8	THN,CLR
P79(Apr'07-Sep'07)	23	18hr	Bright	< 0.6	THN,CLR
P80(Oct'07-Mar'08)	57	06hr	Dark	< 0.8	THN,CLR
P80(Oct'07-Mar'08)	48	06hr	Grey	< 0.8	THN,CLR
P80(Oct'07-Mar'08)	28	06hr	Bright	< 0.8	THN,CLR
P80(Oct'07-Mar'08)	23	06hr	Bright	< 0.6	THN,CLR
P81(Apr'08-Sep'08)	57	18hr	Dark	< 0.8	THN,CLR
P81(Apr'08-Sep'08)	48	18hr	Grey	< 0.8	THN,CLR
P81(Apr'08-Sep'08)	28	18hr	Bright	< 0.8	THN,CLR
P81(Apr'08-Sep'08)	23	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 174 nights (assuming 9 hour 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, magnitudes are Vega). † is the proposed UKIDSS-DXS depth in H over 5 square degrees.

Filter	Time (h) (per source) (no overheads)	Time (h) (per tile) (+overheads)	Time (h) (full survey) (+overheads)	5σ AB	$2''$ ap.mag. Vega	UKIDSS Vega	Seeing	Moon	Transparency
Z	17.5	60.8	570	25.7	25.2	–	0.8	D	THN,CLR
Y	6.7	23.2	218	24.6	24.0	–	0.8	G	THN,CLR
J	8.0	27.9	261	24.5	23.7	22.3	0.8	G	THN,CLR
H	8.0	29.4	276	24.0	22.7	$22^{\dagger}$	0.8	B	THN,CLR
K_s	6.7	23.8	224	23.5	21.7	20.8	0.6	B	THN,CLR

The survey fields are described below (the first three are Spitzer-SWIRE fields), depending on scheduling constraints the number of tiles on each field could be adjusted. However, our preference is that the SWIRE fields accrue the most coverage.

Field	RA-DEC	Total Number of tiles	Total Area (sq.deg)	Total Time nights
ELAIS-S1	0034-43	3	4.5	52
XMM-LSS	0218-05	3	4.5	52
CDF-S	0332-27	2	3.0	34.5
VIDEO-1	1400+05	2	3.0	34.5

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. It is also part of the VVDS shallow survey. If VIDEO-1 is selected as a field then we will actively pursue Spitzer data similar to SWIRE over that area. The number of nights shown assumes 9 hr nights.

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, and we use 2×2 microstepping to allow better Nyquist sampling for this seeing constraint, and a 5 point jitter pattern. To complete a a third of a tile (i.e. 2 pointings) (to ensure reasonable time per OB) with this strategy requires 2866 s (including overheads), which gives a 5σ point source sensitivity of $K_s = 20$ mag. Therefore to reach the full depth with this strategy requires 38 OBs. To reach the full sensitivity over one tile requires 30 OBs each of 2866 s, which equates to 24 hours per tile, and to cover the full 15 sq.degrees requires 224 hours.

For the $ZYJH$ bands we relax the seeing constraint 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 2207 s (including overheads). To reach the full tile depth of $H = 22.7$ (5σ, 2 arcsec aperture) requires 48 OBs of this length (29.4 hours including overheads). For the full 15 sq.degrees this equates to 276 hours in total.

For the $J-$ we use 30 s DITs and NDIT=2, this equates to 2090 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 48 OBs or 27.9 hours per 1.6 sq.degree tile. For the full 15 sq.degree survey area this equates to 261 hours.

In Y we only aim to reach $Y = 24$ (Vega) to ensure that high-redshift quasar candidates can be distinguished from dwarf stars (Fig. 6), 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. Using DIT=30 s and NDIT=2, with a 5-point jitter pattern means that to completely cover one tile requires 2090 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 seperate OBs or 23.2 hours (including overheads). Thus to cover the full 15 sq.degree requires 218 hours.

The $Z-$band observations need to be deeper than in the other bands as this is the filter we will use to probe shortward of the 4000Å at $z > 1$. 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 3128 s (including overheads) per tile, reaching a 5σ depth of $Z = 22.8$. To reach the full survey sensitivity of $Z = 25.2$ requires 70 OBs, taking 61 hours per tile. Therefore, the full 15 sq.degrees requires 570 hours.

Therefore, the full survey requires a total of ∼1550 hours.

We note that currently ESO assumes 9 hour long nights (10 hours in winter and 8 hours in summer), however an extended night for the near-infrared observations carried out with VISTA would ensure that all of the surveys could be carried out at increased efficiency. For instance, K_s-band observations can extend well into astronomical twilight.

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function	Affiliation	Country
M. Jarvis	PI & OB Preparation	Oxford/Univ.Herts.	UK
A. Edge	OB Preparation	Durham	UK
R. McLure	OB Preparation	Edinburgh	UK
A. Verma	OB Preparation	Oxford	UK
CASU(VDFS)	Pipeline processing	Cambridge	UK
CASU(VDFS)	Data Quality Control-I	Cambridge	UK
J. Emerson	VISTA PI & VDFS Coordinator + OB prep	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
R. Ivison	VIDEO-VLA/ATCA cat. production	Edinburgh	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	VIDEO-(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:

The observation planning team will be led by the PI (Jarvis) and include members of the VIDEO team from Edinburgh (McLure), Durham (Edge), MPIA-Heidelberg (Meisenheimer), Oxford (Verma) and Sussex (Loveday & Oliver) and VISTA PI Emerson (QMUL). 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 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 VISTA Data Flow System (VDFS; Emerson et al. 2004, Irwin et al. 2004, Hambly et al. 2004), operated by the VDFS team, and augmented by Jarvis, Gonzales-Solares, Clewley, Smail and Bell, especially for product definition and product Quality Control. This team already has experience with wide-field near-infrared data as Jarvis, Smail, Clewley, Gonzales-Solares are all members of either the UKIDSS-UDS or DXS working groups, and Gonzales-Solares performed the individual frame stacking for the UKIDSS-DXS.

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

6.4 Expected data products from the VDFS:

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
Source re-measurement parameters from consistent list-driven photometry across all available bands in any one field.

We realise that due to the depth of the VIDEO survey that more precise and survey-specific frame-stacking will be required. The VIDEO team will undertake this task and provide the ESO archive with the final stacked data, with merged catalogues from all 5 filters.

The multi-wavelength stacked catalogues will also be made available by the VIDEO team led by Jarvis and the specific task leaders highlighted in table 6.1, these include VIDEO catalogues matched with Spitzer-SWIRE, public Herschel survey data, along with optical, X-ray and radio catalogues over the VIDEO areas.

6.5 General schedule of the project:

T0: Start of observations
T0+12months; Release of science products from first month of survey observations
T0+16month; 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

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 very distant ($z > 2$) candidate (proto-)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. We will also be pursuing moderate depth optical imaging (probably with the VST) where this doesn't already exist, to enable even better photometric redshifts, this data will be particularly useful for the $z < 1$ populations. We note that even to cover 15 sq.degrees would not require an extensive time allocation (typically 30-60 min integrations per filter per square degree).

From Spitzer to Herschel

Spitzer and Herschel are attempting a complementary exploration of galaxy populations as function of epoch and environment - but focusing on the bolometric output from obscured star-formation and AGN activity. It is vital for VIDEO to be in the same fields for scientific reasons (e.g. comparison of different populations in same volume) and for practical reasons (e.g.. multi-wavelength studies of same galaxies, using VIDEO photometric redshifts for Herschel sources etc.)

The ELAIS-S1, CDF-S and XMM-LSS fields form part of the Spitzer Wide-area InfraRed Extragalactic 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. 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 of 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.

Extension of VIDEO

It is clear that to reap the full benefits of the multi-wavelength coverage over the whole of the SWIRE fields deep near-infrared imaging will be crucial. Thus, we envisage that VIDEO could continue beyond the nominal 5 years proposed here as VISTA will still be the premier instrument for conducting this survey, as space-based projects such as WISE will not have the spatial resolution to determine galaxy morphologies nor have the shorter near-infrared wavelength coverage.

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

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