1 Title: A Complete Census and Map of the Universe at $z < 2$

PI: Seb Oliver, Sussex Survey Science Centre, University of Sussex, UK

1.1 Abstract:(10 lines max)

We propose to observe 36 sq deg. in u, g, r, i, z to a 10σ depth $i_{\mathrm{AB}} = 25.0$ covering the southern SWIRE/UKIDSS-DXS fields. These fields are unique for probing stellar mass (UKIRT-J,K, Spitzer 3.6μm) and star-formation (GALEX-UV, Spitzer $\geq 24\mu$m, ATCA 21cm, Herschel $\geq 90\mu$m). We will detect $> 90\%$ of all SWIRE galaxies, $\langle z \rangle \sim 1$ and detect effectively all galaxies whose stellar mass exceeds M_* at $z = 2$ while simultaniously identify about 50% of the far-infrared background at 24μm. 45% of our sample will be detected in 8-bands giving photo-z errors of $\sigma_z = 0.02(1 + z)$. From $0.5 < z < 2$ the survey volume in each $\Delta z = 0.2$ is similar to the SDSS and will be the deep high-z counterpart to SDSS and will provide a similar legacy. Our survey is also the wide counterpart to the deep surveys in the GOODs fields that probe $z > 2$. Our primary theme is to characterise the role of environment and other physical processes stimulating and regulating star-formation and the assembly of stellar mass.

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

2.1 Scientific rationale:

One of the most stunning achievements of observational and computational astrophysics in the last 20 years has been the construction of a predictive description of the growth and distribution of dark matter and cosmic structure. In contrast, our understanding of the formation of galaxies has remained rudimentary, owing to the complexity of the physics which drive the evolution of baryons: gas cooling, angular momentum (non-)conservation, star formation, feedback, black hole accretion, galaxy scale energetic outflows, etc. Thus, rather disappointingly, fundamental aspects of galaxy formation and evolution have remained unclear. What is the role of environment in galaxy formation? Which processes quench galaxy-wide star formation in red sequence galaxies? Which processes drive the build-up of the stellar mass of galaxies in different phases of their lives? Why do so few massive galaxies form stars today?

Large-volume multi-wavelength surveys are the only way to address these fundamental questions of galaxy formation. The Sloan Digital Sky Survey has transformed our understanding of the local Universe, soon this optical picture will be enhanced by local surveys in the NIR with UKIDSS and in the FIR with ASTRO-F. We are now poised to obtain a similar understanding of the $0.5 < z < 2$ Universe (over which time most of the stars were formed Fig *) thanks to an international, multi-facility campaign, constructing the largest deep multi-wavelength dataset — the ultraviolet (Galex) and 3.6μm–170μm (Spitzer, Fig. 1, 2), 1-2.2μm- (UKIDSS-DXS) and ultimately to sub-mm with Herschel and SCUBA-2.

The object of this proposal is to create an optical dataset of unprecedented depth and quality, covering a volume equivalent to the Sloan Digital Sky Survey. This "Census" will sample the younger stellar populations, provide morphological information and *critically* photometric redshifts which will finally enable astronomers to study the physical processes which drive the evolution of galaxies. It will allow us to build a complete picture of the evolution of young and old stars, both obscured by dust and unobscured, over the last 11 billion years. The wide area coverage will allow, *for the first time*, joint study of the evolution of the stellar content of galaxies as a function of their environment, as a function of look-back time. These key observational constraints will test our models of galaxy formation to breaking point, driving them to new levels of realism and uncovering definitively the importance of different physical processes in driving the different aspects of galaxy evolution.

The combined data will provide an immediate and lasting resource for European astronomy, supporting key ESA/ESO facilities UKIDSS, VISTA, Herschel and facilitating VLT exploitation.

2.1.1 Hierarchical paradigm

The idea that cosmic structures grow hierarchically through gravitational instability lies at the core of modern theories of galaxy formation. The paradigm has received impressive support from the detection of fluctuations in the cosmic microwave background radiation. In the hierarchical model, galaxies grow within dark matter haloes, which are built up through mergers with similar sized objects or the accretion of smaller units. Over the past decade, there has been rapid progress in developing models that can predict the full merger and star formation histories of galaxies in hierarchical cosmologies. These galaxy formation models can be combined with high resolution N-body simulations, such as the Virgo Consortium's Millennium Simulation, to give predictions for the spatial distribution of galaxies at different epochs.

Even though the models have enjoyed spectacular successes, such as predicting the clustering behaviour of local galaxies and the abundance of sub-millimetre sources, there remain many outstanding problems. Many of the physical ingredients in the models remain poorly understood and require parameters to be specified in order to make predictions. The key areas in which our understanding of physics of galaxy formation is lacking are the following: (1) How efficiently do haloes of different mass cool gas, the basic fuel for star formation? (2) How does the time-scale for this cold gas to be turned into stars depend on galaxy size and on redshift? (3) How do feedback processes, such as supernova driven winds, regulate the rate of star formation? Do AGN play a role in setting the star formation rate in galaxies?

2.2 Immediate objective:

2.2.1 Star formation & the Assembly of stellar mass

It has become clear that the UV/optical rest-frame color distribution is bimodal, both at the present day (Strateva et al. 2001, Baldry et al. 2004, Fig 7) and out to $z \sim 1$ (Bell et al. 2004; Wiener et al. 2005). In the local universe it is reasonably clear that the bi-modality reflects broad differences in star formation history: red sequence galaxies are devoid of important amounts of ongoing star formation ('old, red and dead'), whereas blue cloud galaxies possess significant amounts of star formation.

Importantly, it seems that the number of galaxies on the red sequence steadily increases from $z \sim 1$ to $z = 0$; large numbers of galaxies systematically turn off their star formation on a global scale, later settling onto the red sequence (Bell et al. 2004; Chen et al. 2003; S. Faber, priv. comm.). A main goal of this proposal is to understand the physics driving the build-up of the non-star forming galaxies. VST-Census's optical data and photometric redshifts are accurate enough to directly observe the evolution of the bimodal galaxy population. The accompanying UV and IR data from GALEX and Spitzer provide accurate measures of unobscured and obscured star formation for actively star-forming galaxies, allowing discrimination between merger-induced bursts and gas consumption. Spitzer near-IR colors allow study of even obscured AGN using [3.6]-[4.5] colors.

Key Goals: To quantify the obscured/un-obscured star-formation rates and their evolution as a function of stellar mass and in different environments (Sec. 2.2.3).

Methods: Luminosity functions in bands that probe star-formation, UV, U, FIR, Radio (Fig. 6). Luminosity functions in bands that probe stellar mass, r, J,k, 3.6μm(Fig. 5). Bi-variate Luminosity functions to explore SFR vs Stellar mass LFS calculated using photo-z and inversion techniques(Fig. **??**).

Requirements: Depth to reach high redshift. Good broad-band photo-z. Large area to provide very large statistical samples. Well studied fields at UV, IR and Radio wavelengths to provide different SFR tracers.

2.2.2 Extremely massive galaxies, Fig. 10.

A basic prediction of LSS formation models is that the most massive galaxies we see locally ($> 10^{12} M_\odot$) formed within the most massive dark matter haloes ($> 10^{14} M_\odot$) at high redshift (Somerville et al 2001) . There are two direct observational tests of this prediction. Firstly, massive galaxies at high redshift should reside within rich environments, corresponding to further galaxy formation within each halo. Secondly, the haloes themselves should cluster strongly together (Kauffmann et al 1999), due to 'bias' introduced within the models to explain LSS at $z < 1$. As very massive galaxy formation lies at the extreme end of model predictions, the formation and evolution of these galaxies (and thus their environmental richness and clustering strength as a function of redshift) depend sensitively on model parameters, and so are an excellent test of the models.

Testing these predictions is however very difficult. Very massive galaxies (and thus the haloes they are predicted to form within) are extremely rare on the sky, so such a test requires a large enough survey volume to sample a statistically significant number of $> 10^{14} M_\odot$ DM haloes, imaged deeply enough to select and charaterize both the very massive galaxies themselves, and companion galaxies in their local environments. With Census these goals are, for the first time, achievable; our survey volume is predicted to contain between 20 and 70 $> 10^{14} M_\odot$ DM haloes over $1 < z < 2$ (Benson et al 2001, Jenkins et al 2001), more than enough to measure halo-halo spatial clustering. The existing near/mid-IR data, and the optical data proposed for here, can detect galaxies of even moderate mass out to $z < 2$, and so can measure environmental richness (Hill & Lilly 1991). VST Census will therefore provide an unbiased test of predictions for the formation of very massive galaxies.

Key Goals: Measure spatial clustering and environmental richness as a function of redshift. Detect galaxies that represent rare, transition phases in galaxy life-cycles. What are the most massive galaxies at each epoch?

Methods: multi-colour space searches for unusual objects.

Driving requirements: Large Area. Multi-wavelength. Deep enough that even upper-limits are meaningful. Uniformity over wide areas to allow accurate assessment of number densities.

2.2.3 The role of environment in galaxy formation

Finally and most importantly, VST-Census's wide coverage allows exploration of the environment of galaxies, permitting one to explore the build-up of non-star-forming galaxies in different environments. This can be adressed in three ways. (1) Directly studying the star-formation distribution in different densisty regions from groups (lower density environments cannot be identfied with our photo-z), up to rich clusters (2) measuring and comparing galaxy clustering in different population (3) comparing galaxy and dark-matter clustering via weak lensing.

Galaxies form first in clusters thus at a given epoch clusters provide the most dated archaeological remains and deepest probe of galaxy formation. They also form ideal probes of the influence of environment on gal

The large VST Census volume will also 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 and emission line strength can be measured robustly. Such measurements will provide important new constraints on the models at high redshift. 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.

Key Goals: Evolution of galaxy populations in rich environments. Evolution of galaxy clustering and bias on scales approaching non-linear $>\sim 10h^{-1}$Mpc as function of stellar mass and star-formation rates.

Methods: Identify clusters with IR variants of red-sequence method Muzzin A.V., et al.2004, Gladders & Yee (2000). $w(\theta)$ photo-z slice and inversion via Limber's equation. Radially average σ, π diagram. Galaxy-galaxy lensing (Goldberg & Bacon 04). Weak lensing inversion for projected density (Kaiser & Squires 1992, Taylor 01, Bacon & Taylor 03)

Key Requirements: Large-area, depth to probe representative galaxies. Good imaging quality in deepest band for lensing analysis.

2.2.4 Active Galactic Nuclei

There is much speculation about the connection between Active Galact Nuclei and aglaxy evolution. There is a clear relation between central black hole mass and total stellar mass and the globally aeverage luminosity densities of galaxies and AGN show similar trends. AGN may be triggered by mergers and have been postulated as an regulator of star-formation, so might be a key feedback mechanism. It is thus vital to trace AGN activity alongside our study of galaxies.

The coverage of our fields by *Spitzer* will allow an easy identification of Type-II AGN candidates (Hatziminaoglou et al. 2005). An updated version of the Xu et al. (2003) models predicts some 440 AGN (types I and II together) per deg^2 with redshifts up to 4 and detections in all IRAC bands and the MIPS 24 μm channel with some 20 $z > 3$ objects per deg^2. From extrapolation of other surveys (e.g. CFRS, Shade et al. 1995; Faint Galaxy Redshift Survey, Glazebrook et al. 1995; VIMOS, LeFèvre et al. 2004), we estimate the detection of some 1000 classical (UVX) quasars per deg^2 down to $g \sim 26$, i.e. a total of 33000 quasars in the proposed area and the vast majority of the optically selected AGN will have at least one IR data-point. Large part of the proposed fields have X-ray and UV coverage. These spectral energy distributions spanning from the X-rays down to the far-IR will allow us to separate AGN and starformation activity and coupled with the large size of the sample to very faint optical magnitudes will permit, for the first time, the joint study of galaxy & AGN evolution.

Key Goals: Relation between AGN and galaxy evolution.

Methods: Evolution of optical, UV, FIR, and X-ray selected AGN LFs in same volume. Evolution of bi-variate Galaxy/AGN LFs.

Key Requirements: Multi-epoch data to identify (and correct for) variability. Good imaging data for AGN classification. Fields with X-ray, UV and FIR data. Large Area as AGN intrinsically rare.

Figure 1: 0.14% of the SWIRE IRAC data. An IRAC (3.6/4.5/5.8/8.0μm) colour composite taken 20 arcminute across from the ELAIS N1 field, Lonsdale et al. 2004. This probes to $S_{3.6} > 5\mu$Jy or

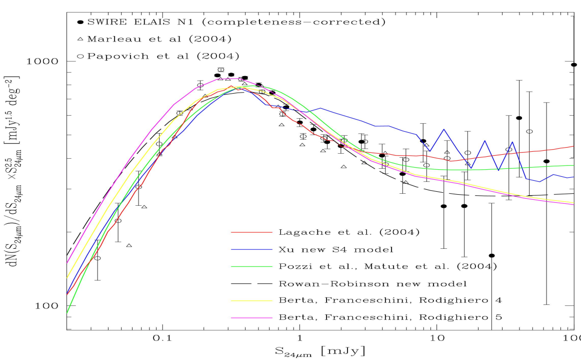

Figure 2: The SWIRE 24 μm number counts Shupe et al. in prep. Shows clear evolution.

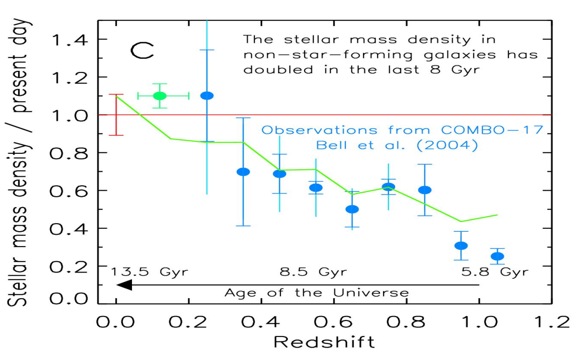

Figure 3: Build up of non-star-forming galaxies: The build-up of the non-star-forming galaxy population, from COMBO-17. The physical drivers of this evolution are unclear

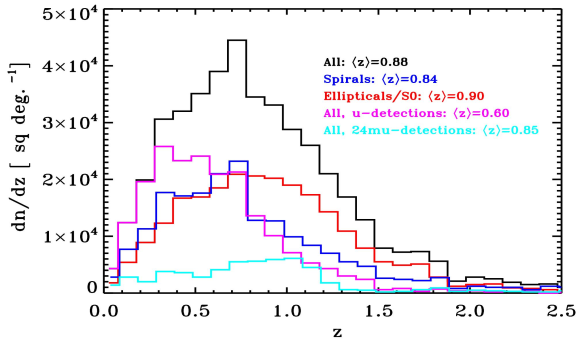

Figure 4: Redshift Distribution $N(z)$. All galaxies detected by Spitzer at 3.6μm$S_{3.6} > 5\mu$Jy. Star-forming systems (blue); passive systems (red) and AGN (green). Galaxies detected in u (cyan) a 24 μm (magenta)

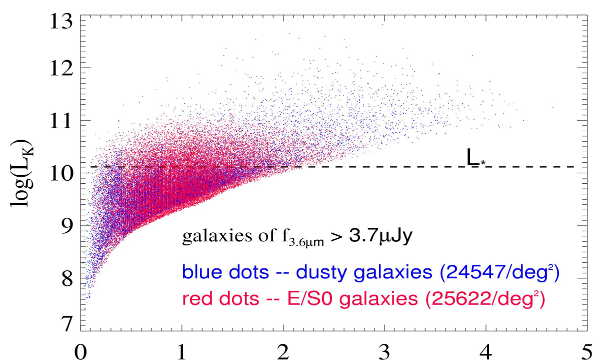

Figure 5: K-band Luminosity redshift plane for galaxies targeted in this proposal showing complete coverage of the stellar mass to high redshift. From the models of Kevin Xu [?] flux limited 3.6μm limit, $> 5\mu$Jy

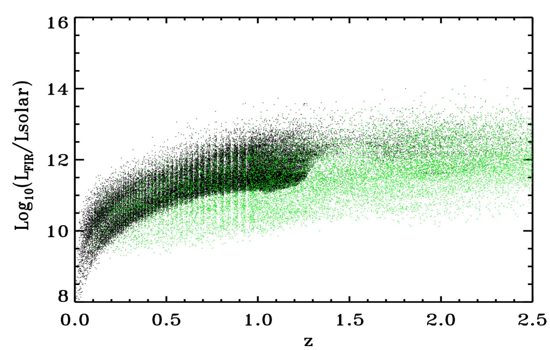

Figure 6: FIR Luminosity redshift plane for galaxies targeted in this proposal. (AGN in green) showing good coverage of the star-formation rate distribution functions. From the models of Kevin Xu [?] flux limited at the SWIRE 24μm limit, $> 200\mu$Jy

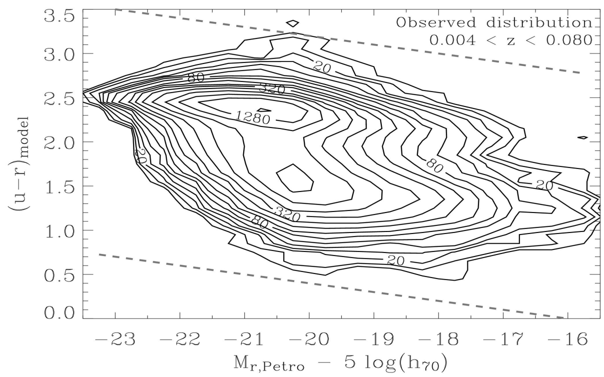

Figure 7: The bimodal color–magnitude relation from Baldry et al. 2004. Clear segergation into active/passive systems.

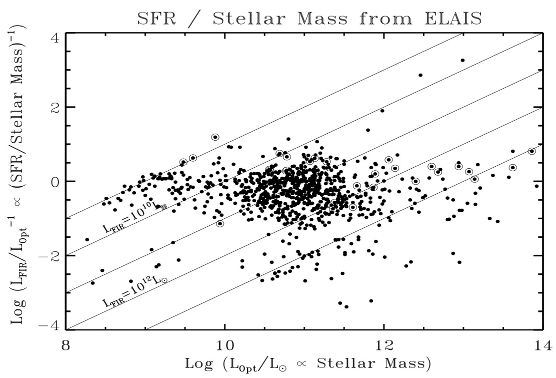

Figure 8: The bimodal color–magnitude relation in FIR from Oliver & Pozzi 2005. N.B. passive systems are almost absent and a third excetptionally active system ($y \approx -2$) is revealed.

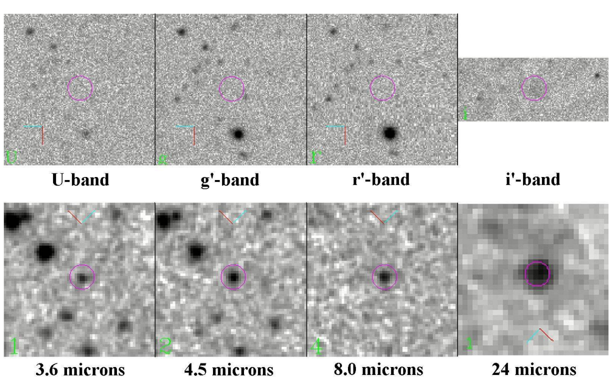

Figure 9: Example extreme object from SWIRE: Postage stamps. This object was detected using mixtures modelling of the four IRAC fluxes. Extreme objects like this can be detected using all bands in the VST-Census archive.

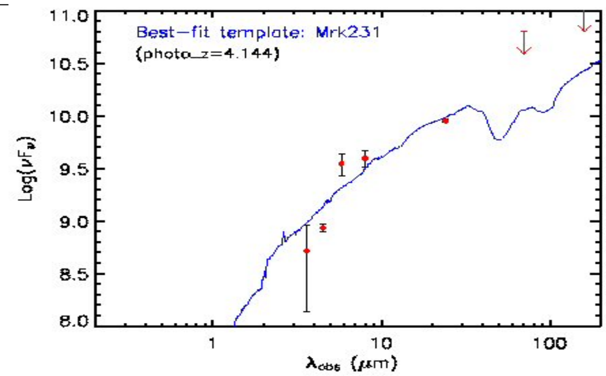

Figure 10: Example extreme object from SWIRE: SED, the object might be at $z \approx 4$ and the most luminous object in the Universe. Deep optical data are essential for detecting and characterizing objects like this.

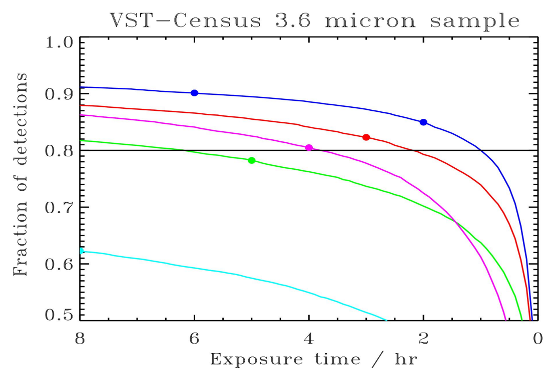

Figure 11: Detection fraction of spiral galaxies as a function of exposure time: u-cyan; g-green, r-red; i-blue, z-magenta. i is the most efficient for detecting SWIRE sources and thus stellar mass and star-formation. Identification fractions are from simulated SWIRE catalogues using the model of Xu et al. [?]

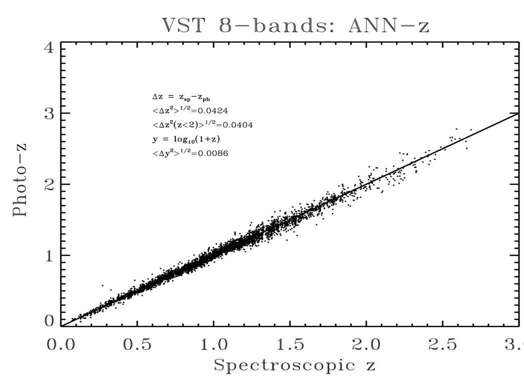

Figure 12: Photometric redshift simulation. Galaxies detected in in all 8-band $u, g, r, i, z, J, K, 3/6\mu m$ from VST/UKIDSS/SWIRE. This represents 45% of all galaxies detected in the rest-frame NIR by SWIRE

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

3.1 VST-16

There is a strong liaison between this project and the Guaranteed Time project VST-16.

VST-16 will primarily be undertaking medium-band imaging which provides a more accurate photometric redshifts, though they cannot cover as large an area. VST-16 ultimately hopes to cover 17 sq. deg.

The VST-16 goals also require broad-band imaging over the full 17 sq. deg. to achieve their desired photo-z accuracy. They are only planning to complete 5 sq. deg. in their guaranteed time and are expecting the remaining 12 sq. deg. to be completed by this proposal.

VST-16 aims to reach a depth of $R \approx 24$ while VST-Census aims to reach $i = 25$.

Take together VST-16 and VST-Census will cover 17 sq. deg. with 16 bands and photo-z errors better than $\sigma_z = 0.01(1+z)[1+(1/SNR)^2]^{1/2}$ $0.2 < z < 1.1$ and 36 sq. deg. deeper but with poorer photo-z.

The VST-16+VST-Census combination will be able to tackle questions of the role of star-formation vs stellar mass and environment in galaxy formation to lower densities and smaller scales (Section 2.2.1, 2.2.3) while VST-Census alone will be able to explore higher redshift and rare populations, large scale structure, clusters, and the impact of environment in the (rarer) densest regions far better than VST-16 can (Section 2.2.2 2.2.3.

3.2 CFHTLS and other Optical surveys

The vast majority of our goals hinge upon uniformity and the unique Spitzer/UKIDSS/GALEX data from the SWIRE + DXS fields which allow us to accurately measure star-formation and stellar mass. The CFHTLS and other optical surveys may have similar aims. However, no surveys cover even a significant fraction of SWIRE fields to the required depth.

The CFHTLS only covers one SWIRE field (XMM-LSS) i.e. 9. sq.deg. Thus only a small fraction of the science in this proposal can be done using CFHTLS data.

It is essential that we cover the XMM-LSS field even thought it will be covered by CFHTLS. This is because we want to provide a homogeneous legacy product, without this duplication most projects will be done either on the XMM-LSS field or the VST-Census fields and rarely both together. N.B. almost all SWIRE science at the moment is being done on sub-sets of the SWIRE data because there is no uniform optical coverage. There is also a rich database of spectroscopic redshifts in the XMM-LSS field and these will able to improve the calibration of the photo-z methods for the full VST-Census sample. Finally the access to the CFHTLS data is restricted and the proprietary period is long, whereas we will be undertaking a public survey ensuring maximum and rapid exploitation of the data in these fields and rapid provision of targets for VLT and other facilities (see Section 7).

4 Observing strategy: (1 page max)

Survey homogeneity of exposure and calibration is vital for good photometric redshift and to maximize legacy. Though *Jitter* mode provides uniform coverage it does not allow for chip-chip variations or to use chip-chip cross-calibration. On the other hand we expect that the overheads will be higher for a *Dither* mode. We thus opt for a combined *Jitter/Dither* mode. We maximize the total number of frames per pointing for the best uniformity and quality control. The resulting shorter exposure times also reduce the problems of saturation. With a readout time of 45s we can afford exposure times as short as 7.5 mins at little cost and high benefit. In every Observation Block we also include one very short (overhead limited) exposure to account for very bright stars.

We recognize that some science goals require complete single-band identification over the whole field as early as possible while some goals (particularly in the centre of fields where additional complementary data exists) require deep multi-band data we have thus devised an expanding "core" and flanking fields model for the long-term plan.

- Observing mode: *Jitter & Dither*. We have allowed for a minimum of 15 frames per mosaic position $N_{\rm frames}$. These will be split into $N_{\rm jitter} \times N_{\rm dither}$. $N_{\rm dither}$ is set to 5 to ensure good coverage and is consistent with the standard observing modes of Omega-Cam. This maximizes $N_{\rm jitter}$ number of jitter pointings at each dither and ensures
- Observing Strategy: *Deep*. We will split the observations into Observing Blocks (OBs) of about one hour or under. With the exception of u an OB will consist of all *Jitter* frames at a number of *Dither* positions and different *Dither positions* will be included in different OBs as required. For u some of the jitter positions will be included in different OBs.
- Observing Strategy: *Mosaic*. All fields will be 3×3 which provides a uniform data product and is the minimum mosaic to cover all the SWIRE data in each field. Pointings will overlap to allow for quality control and calibration.
- Standards: beginning, middle and end of night. Is there an atmospheric monitor?
- i will always be done in better seeing conditions.
- Observations will take place over three years
- i will cover the whole of each field with 2hr exposures every year for time/variability measurements.
- In u, g, r, z we will define a core areas in each field. The core areas will be done to the final depth as early as possible and the core will expand each year. All areas outside will be covered to a shallower depth and this depth will be increased each year.

5 Estimated observing time:

Period	Total Time (h)	Mean RA	Moon	Seeing	Transparency	Mosaic
ELAIS-S1	234	00h39m	dark/grey	1	clear	3×3
SWIRE-CDFS	234	03h32m	dark/grey	1	clear	3×3
XMM-LSS	234	02h21m	dark/grey	1	clear	3×3
SA22/VIMOS-4	234	22h18m	dark/grey	1	clear	3×3

Table 1: Fields and conditions

	Omega-CAM				
band	u	g	r	i	z
λ	0.35	0.48	0.63	0.77	0.90
$zp_{\rm Vega}$	7.9	8.97	8.74	8.50	8.37
$zp_{\rm exp}$	24.7	25.1	24.5	24.0	22.7
$t_{\rm exp}$/hr	8	5	3	6(2)	4
$t_{\rm frame}$ /min	13.	15	8	8	9.6
$N_{\rm frame}$	35	20	15	45 (15)	25
$N_{\rm jitter}$	7	4	3	3	5
$N_{\rm Dither}$	5	5	5	15 (5)	5
$m_{\rm Vega}$	24.8	26.1	25.0	24.6(24.0)	23.0
$m_{\rm AB}$	25.8	26.0	25.1	25.0(24.4)	25.0
Flux/ μJy	0.18	0.14	0.32	0.36(0.62)	1.4
% ID elliptical	33	66	76	90(81)	78
% ID spiral	62	78	82	90(85)	81
% ID all	46	72	75	90(83)	79

Table 2: Parameters for this survey. The three sections indicate: assumptions; definition of the survey and scientific consequences/drivers. Exposure time zero points are determined using the 10σ, 10,000s limits given on the Omege-CAM WWW site http://www.astro.rug.nl/õmegacam/documents/p in parentheses for i are the depth in a 2 hour exposure which will be the depth we get over the full survey area every year. Identification fractions are from simulated SWIRE catalogues using the model of Xu et al. [?], updated for first Spitzer results and are illustrated in 11

. The total exposure is 25 hours per pointing. With a total area of 36 sq. deg. this amounts to 936 hours in all or 117 (clear) nights, excluding overheads. The main time requirements is set by our area, depth and photo-z requirements, discussed in [?]

5.1 Time justification: (1 page max)

5.1.1 Area

Objective 2.2.1: To acheive the same numbers of sources in given colour/mag galaxy sub-classes as Fig 7 from a sub-set of SDSS (2400 sq. deg. $0.0004 < z < 0.08$) requires the same co-moving volume of $3.2 \times 10^6 (h^{-1}\mathrm{Mpc}^3,$). With the same $\Delta z = 0.08$ but at $z = 1$ this requires 14 sq deg. To obtain the same precision in four sub-samples selected on the density of their environments e.g. rich clusters/poor clusters/groups/field demands increasing the area to 36 sq. deg. even allowing an icrease in $\Delta z = 0.12$ i.e. $\Delta t = 0.5$Gyr. Four fields each spanning $120h^{-1}$Mpc scales at $z = 1$ also ensures that we have a fair sample of the Universe. **Objective 2.2.2:** To detect the rare, luminous and transitory phenomena obviously requries the maximum volume. The main boundary is the limitation of complementary data and indeed most of our goals require the multi-wavelength coverage to sample the rest-frame NIR (from UKIDSS-DXS and/or SWIRE-IRAC) and the star-formation from the UV (Galex) and mide-IR (SWIRE). The 3×3 in each of the four southern fields covered by SWIRE and/or UKIDSS is the minimum to include all data from those projects. **Objective 2.2.3:** Rich clusters have a space density of 1/sq.deg. To obtain at least six in six different redshift bins thus requires an area of 36 sq. deg. Above a critial number density (1 galaxy per scale length^3) clustering statistics depend on the volume of the survey and the fractional error (σ_{2pt}) in 2-pt statistics $\sigma_{2pt} \approx \sqrt{2/M}$ where M is the number of independent cells on the scale of interest. On $10h^{-1}$Mpc scales and $z = 1$ we can thus measure the clustering in any shell with 5% accuracy.

5.1.2 Photo-z

Baldry et al. used a resolution in absolute magnitude of $\Delta m = 0.5$, assuming this width could be $\pm 2\sigma_m$ this sets a requirement on photo-z accuracy of $\sigma_z = 0.15$, easily acheivable. To measure luminosities accurately and to explore clustering on small scales we need more accurate photo-z We have taken the GalICS (Guiderdoni et al.) semi-analytic model to give roughly the right distribution of galaxy magnitudes, redshifts and a wide range of spectral energy distributions. We then demanded detection in all 8-bands $u, g, r, i, z, J, K, 3/6\mu m$ from VST/UKIDSS/SWIRE. We trained the Artificial Neural Network code (Collister et al. 2004) on a sub-set of the data and testing on a different sub-set and obtained an accuracy of $\sigma_z = 0.02(1 + z)$ (Fig **??**). With 4/8 bands and using a template fitting we find $\sigma_z < 0.08(1 + z)$.

5.1.3 Depth

Our basic depth requirement are to detect $> 70\%$ of all stars at $z < 1.5$. This requirement is met by the SWIRE 3.6μ and UKIDSS-DXS limits so our optical depth requirements are to detect at least 90% of the SWIRE spirals and 90% of ellipticals/spheroids in at least one band and to detect more than 80% of all sources in 4 bands and $\sim 50\%$ of all sources in the u-band. To test this we have used updated simulated catalogues from Xu et al. (2003), results are summarized in Table 2 and Fig 11. The most sensitive band in terms of detection fraction in a given observing time is i. 6 hour exposure in i gives us more than 90% detections in both populations and 92% over-all. As described in Section 4 we propose to split this 6hr into 3×2 hr and a 2 hr exposure would still detect 83% of all sources.

The primary selection for Baldry et al. 2004 was $r < 17.5$ and $u - r$ colours were mapped with significant contours as reds as $u - r \approx 3$. To map the same extend in Luminosity $z = 1$ we need to go as deep in rest-frame r (i.e. a NIR band) to an AB magnitude of 22.5 and do so with either UKIDSS-DXS or SWIRE 3.6 μm (Table 3). To reach a rest-frame $u - r = 3.0$ colour would naively require a depth in $rori$ of $m_{\mathrm{AB}} \approx 25.5$. Our survey does not quite reach this, however, the redest galaxies are the most luminous which will compensate.

Lensing also places depth requirements, in order to obtain good density information for galaxies at $z \simeq 0.5$, we require deep imaging of galaxies up to $z \simeq 1$.

5.1.4 Imaging and epoch requirements

In addition, we require good quality images in order to measure lensing distortions; Bacon et al (2001) showed that seeing $< 0.9''$ is highly desirable; we will therefore use our best seeing for i-band exposures. We have recently learnt that their may be fringing problems with i and if these are confirmed we may consider doing our lensing work in r and even selecting our deeper fields to be in r, even though this is less efficient for detecting SWIRE sources. Multiple epochs are essential for detecting and correcting for (monochromatic) quasar variability.

6 Data management plan: (3 pages max)

We shall 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; database ingestion of pipeline products; production of enhanced database-driven products, including federation of VST survey products with UKIDSS surey products; dissemination via a purpose-built science archive with Virtual Observatory services using IVOA standards; delivery of survey products to the ESO/STECF Science Archive Facility(SAF)

The VDFS is a systems-engineered project that is being employed for the UKIRT WFCAM and VISTA infrared surveys that are complementary to VST public surveys in the optical, and 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 pipeline processing component of the VDFS has been scientifically verified by processing wide field mosaic imaging data using a range of existing CCD mosaic camera e.g. ESO WFI, CFHT 12K and MegaCam, CTIO Mosaic, KPNO Mosaic AAO WFI, INT WFC and WHT PFC. It has also been used to process ESO ISAAC data e.g. the FIRES survey data, and recent commissioning data from UKIRT WFCAM.

6.1 Team members:

Name	Function	Affiliation	Country
Seb Oliver	0. PI/Planning	Sussex	UK
Richard Bower	1. Planning	Durham	UK
Philippe Heraudeau	1. Planning	Kapteyn Ast. Inst.	Netherlands
Brian Siana	1. Planning	UCSD	USA
Eduardo Gonzalez-Solares	2. Data Processing	Cambridge	UK
Richard McMahon	2. Data processing	Cambridge	UK
Mike Irwin	2. Data Processing	CASU	UK
Dave Shupe	2. Data Processing	IPAC	USA
Francesca Pozzi	3. Quality	Bologna	Italy
Evanthia Hatziminaoglou	3. Quality	IAC	Spain
Ismael Perez-Fournon	3. Quality	IAC	Spain
Duncan Farrah	3. Quality	IPAC	USA
Giulia Rodighiero	3. Quality	Padova	Italy
Stefano Berta	3. Quality	Padova	Italy
Anthony Smith	3. Quality	Sussex	UK
Ian Waddington	3. Quality	Sussex	UK
Jon Loveday	3. Quality	Sussex	UK
Kathy Romer	3. Quality	Sussex	UK
Payam Davoodi	3. Quality	Sussex	UK
Michael Rowan-Robinson	4. Photo-z	Imperial	UK
Tom Babbage	4. Photo-z	Imperial	UK
Mari Polleta	4. Photo-z	UCSD	USA
Carlotta Gruppioni	5. Modelling	Bologna	Italy
Kevin Xu	5. Modelling	Caltech/IPAC	USA
Carlos Frenk	5. Modelling	Durham	UK
Carlton Baugh	5. Modelling	Durham	UK
Cedric Lacey	5. Modelling	Durham	UK
Veronique Buat	5. Modelling	Marseille	France
Alberto Franceschini	5. Modelling	Padova	Italy
Peter Thomas	5. Modelling	Sussex	UK
Serena Bertone	5. Modelling	Sussex	UK

Name	Function	Affiliation	Country
Andy Taylor	6. Lensing	Edinburgh	UK
David Bacon	6. Lensing	Edinburgh	UK
Megan Gray	6. Lensing	Nottingham	UK
Matt Griffin	7, Liaison-HSO-SPIRE	Cardiff	UK
Andy Lawrence	7. Archiving	Edinburgh	UK
Carol Lonsdale	7. Archiving	IPAC/Caltech	USA
Jim Emerson	8. Archiving	Queen Mary, London	UK
Matthew Colless	8. Liaison-AAOmega	AAO	Australia
Paolo Ciligi	8. Liaison-ATCA	Bologna	Italy
Rob Ivison	8. Liaison-ATCA	Edinburgh	UK
Gavin Dalton	8. Liaison-FMOS	Oxford	UK
Bruno Milliad	8. Liaison-GALEX		France
Marie Trayer	8. Liaison-GALEX		France
Dieter Lutz	8. Liaison-HSO-PACS	MPE, Garching	Germany
Ian Smail	8. Liaison-SCUBA-2	Durham	UK
Steve Rawlings	8. Liaison-SKA	Oxford	UK
Gene Smith	8. Liaison-SWIRE	UCSD	USA
Alastair Edge	8. Liaison-UKIDSS	Durham	UK
Steve Warren	8. Liaison-UKIDSS	Imperial	UK
Will Sutherland	8. Liaison-VISTA	Cambridge	UK
Eric Bell	8. Liaison-VST-16	MPIA Heidelberg	Germany
Klaus Meisenheimer	8. Liaison-VST-16	MPIA Heidelberg	Germany
Ivan Valtchanov	8. Liaison-XMM-LSS	Imperial	UK
Marguerite Pierre	8. Liaison-XMM-LSS	Paris	France
Aprajita Verma	8. Liason-HSO-PACS	MPIA	Germany
Manfred Stickle	8. Liason-HSO-PACS	MPIA Heidelberg	Germany

6.2 Detailed responsibilities of the team:

Experience with SWIRE 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 Scientific Working groups (following the themes of the goals listed in the Objectives). Any problems found by these teams will be addressed by the appropriate Functional Working Groups. All team members will be free to join whichever Science Working Groups they wish to.

6.2.1 Observation Planning

The observation planning team is a sub-set of the Data Processing and Quality control teams. They are responsible for generating the OBs and revising these.

6.2.2 Data Processing

The Cambridge Astronomy Survey Unit (CASU) will lead the Data Processing activity and have the hardware and people resources required to process the data from any UK led VST program. IPAC have additional experience in large volume data flow systems and mosaic stacking in particular and will support this activity. The Data Processing team are responsible for producing all Level 1/2 products.

6.2.3 Calibration & Quality Control

The Quality control team is primarily Sussex, MPIA, Durham. They will carry out a series of specific checks to validate the products from the data processing pipeline. In particular this includes matching sources detected in overlap regions and correcting/checking the calibration using a multi-colour generalization of the plate-matching techniques. This team is responsible for validating all Level 1/2 products.

6.2.4 Photo-z, Modelling & Lensing

Accurate and well understood photo-z are an essential part of the data product. Photo-z team includes experts at various institutes. They will compare and contrast their methods and help ensure the adequate calibration data are obtained. They will be responsible for producing a photometric redshift catalogue (Level 3.1)

The modelling team includes Sussex, Durham, IPAC, Imperial, Padova. They will provide phenomenological, semi-analytic and numerical models of the survey. They will be responsible for providing mock-catalogues (Level 3.2).

The lensing team is based at Ediunburgh and will produce lensing mass maps.

6.2.5 Archiving

The archiving team is Vista Data Flow Sustem Team. They are responsible for ensuring a robust and versatile data storage and access to the world community. IfA will also ingest the data into the UKIDSS/VISTA archive (a component of ASTRO-Grid) and IPAC will archive the data in IRSA (as has been done with the SWIRE data).

6.2.6 Survey Liaison

Some individuals are members of related surveys and will provide key liaison between the different projects.

6.3 Data reduction plan:

6.3.1 Data reduction pipe-line

The data processing pipeline will be based on the CASU Vista Data Flow System (VDFS) infrastructure and code. Versions of this have already been used to successfully process wide field optical mosaic camera data from a wide range of systems including: ESO 2.2m WFI, CFH 12k, CFH MegaCam etc.

The VDFS pipeline shall be used for all processing. This follows well defined processing steps and is a modular design so that extra steps are easily added. All the steps have been tested on a range of input datasets.

6.4 Expected data products:

There are different levels of data products, L1-L4 representing an increased level of sophistication and corresponding understanding of the data. Different data product levels will be released at each data release. In L2.3/L2.5 we distinguish between Deep and Homogeneous products which have different scientific purposes.

- L0.1: Raw data frames
- L1.1: photometrically calibrated, single pointing maps
- L1.2: Jitter stacked maps
- L1.3: single-band catalogues from single pointing & jitter-stacked maps
- L2.1: band-merged catalogues from single pointing & jitter-stacked maps
- L2.2: Dither stacked maps
- L2.3: Deep single-band & band-merged catalogues from Dither stacked maps
- L2.4: completeness and error estimates for catalogues
- L2.5: Homogeneous single-band & band-merged catalogues from Dither stacked maps
- L3.1: photo-z catalogues
- L3.2: mock catalogues
- L3.3: Lensing maps
- L4.1: simulation tools for estimating full selection criteria (best efforts)

6.5 General schedule of the project:

We anticipate the observing to take place over three years. There will be four data releases, the first three will be scheduled after the new data has been validated which we expect to take less time each year. Each data release will include new data, revised versions of previous data and new types of data products. The final products will be released three years after the first cycle of observations have been completed. We assume that raw data products (Level 0) will be released immediately by ESO, if not we shall release raw data frames through our archive routes as soon as possible.

- **T0: Spring 2006** First Epoch Observations
- **T0 + 0months:** Version 0: Level 0 Products released
- **T0 + 9months:** Version 1: Level 1 Products released
- **T0 + 12months:** 2nd Epoch Observing
- **T0 + 18months:** Version 2: Level 2 and revised Level 1 products
- **T0 + 24months:** 3rd Epoch Observing
- **T0 + 27months:** Version 3: Level 3 and revised Level 1& 2
- **T0 + 36months:** Version 4: Final versions of all Level 1-3 products.

7 Envisaged follow-up: (1 page max)

7.1 Imaging Surveys

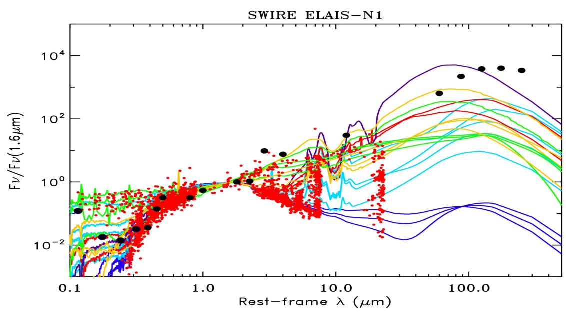

Figure: A compilation of rest-frame photometry for galaxies from the SWIRE data set together with a set of template SEDs. These galaxies all have known redshifts and have been fitted with template SEDs and then normalized in the rest-frame H-band (1.6μ). At z=1 and the SWIRE flux 3.6μm band is in the H-band and the 5 σ limit is 3.7μm Jy. Proposed optical depths are indicated. All

Spitzer data for SWIRE have now been taken. A Spitzer proposal is being submitted to match the SWIRE-IRAC observations in the SA22/VIMOS-4 field. All the fields of the present proposal are included in the deep imaging survey of GALEX. The observations are almost completed (more than 50ATCA observations covering 6 sq. degrees of S1 are ongoing. UKIDSS observations are planned with first light this month. APEX/LABOCA and/or JCMT/SCUBA2 could map areas of 10 square degrees and are likely to target these regions. When VISTA is operational it is unquestionable that it should cover the two SWIRE fields not accessible to UKIDSS, completing the homogeneous coverage. It is reasonably feasible to do at least the two Southern fields with VISTA to approx 1 mag deeper than UKIDSS-DXS / Table 3 , i.e. $K_{\rm Vega} \sim 22.0$ These fields will be the target of intense scrutiny by Herschel which will provide a full characterization of the rest-frame FIR emission. Herschel surveys with SPIRE in particular will require the Spitzer data for identifications and so are bound to follow SWIRE fields. Virtually every source at the confusion limit of SPIRE will be detectable by SWIRE. Thus these optical surveys will allow the very rapid exploitation of Herschel. These surveys are summarised in Table 3 and Fig. *.

7.2 Redshift Surveys

Redshift surveys will permit studies of environment at lower densities, clustering on smaller scales and cosmological parameter estimation. These Census data will provide the necessary targeting data for substantial deep redshifts surveys of significant subsets of this survey would be carried out with VIMOS and (for equatorial fields) the FMOS on Subaru. Brighter but fully sampled redshift surveys could easily be undertaken with the new AAOmega instrument on AAT. Redshift surveys will allow us to explore some science goals in more detail (e.g. 2.2.1,2.2.4) but they will also provide the important training information to fully characterize photo-z methods enabling the full data set to be used for all science goals.

7.3 Targeted observations

The large volume allows us to find rare objects including ULIRGs and clusters (Sections 2.2.2 2.2.3). These can then be targeted individually with VLT, Alma, JWST etc.

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

This proposal will help fulfill ESOs promise to provide supporting data for Spitzer Legacy programs as given is an Open Letter to the community from Catherine Cesarsky ESO Director General on 13th September 2000 (see http://www.eso.org/observing/misc/20000824.sirtf.html)

> For these reasons, ESO takes responsibility for coverage from the observatories at La Silla and Paranal for all the approved Legacy Programs which have a substantial participation from the ESO community. ESO will ensure that appropriate allocation of time on relevant instruments, in line with the scientific goals of approved [Spitzer] Legacy programmes, is made in a timely manner. In the spirit of all the Legacy Programs, the resulting data will be immediately made public worldwide.

It should be noted that SWIRE is the Spitzer Legacy survey with the largest proportion of ESO members.

This proposal is requesting a substantial amount of time, 936 hrs, it is interesting to note that this is very similar to the amount of time Spitzer dedicated to SWIRE (850 hrs) and the time planned for UKIDSS-DXS (826 hrs).

References

Strateva et al. 2001,

Chen et al. 2003 Baldrey et al. 2004 Bell et al. 2004 Wierner et al. 2005

Muzzin A.V., et al.2004AAS...20517809M Gladders & Yee (2000). Benson A. J., et al, 2001, MNRAS, 327, 1041 Jenkins A., et al., 2001, MNRAS, 321, 372 Hill G. J., Lilly S. J., 1991, ApJ, 367, 1 Somerville R. S., et al, 2001, MNRAS, 320, 504 Glazebrook et al., 1995, MNRAS, 273, 157 (Goldberg & Bacon 04) Kaiser & Squires 1992, Taylor 01, Bacon & Taylor 03) Hatziminaoglou et al., 2005, AJ, issue March 2005

LeFèvre et al., 2004, A&A submitted, astro-ph/0409133

Schade et al., 1995, ApJ, 451

Xu et al., 2003, ApJ, 587, 90

Emerson J.P. et al., 2004, "VISTA data flow system: overview", in Optimizing scientific return for astronomy through information technologies, eds. P.J. Quinn & A. Bridger, Proc. SPIE, vol. 5493, 401

Irwin M.J. et al., 2004, "VISTA data flow system: pipeline processing from WFCAM and VISTA", in Optimizing scientific return for astronomy through information technologies, eds. P.J. Quinn & A. Bridger, Proc. SPIE, vol. 5493, 411

Hambly N.C. et al., 2004, "VISTA data flow system: survey access and curation; the WFCAM science archive", in Optimizing scientific return for astronomy through information technologies, eds. P.J. Quinn & A. Bridger, Proc. SPIE, vol. 5493, 423

Inst.	GALEX		WFCAM			IRAC				MIPS		PACS		SPIRE		
band	FUV	NUV	J	H	K	1	2	3	4	24	70					
λ/μm	0.15	0.23	1.	1.6	2.2	3.6	4.5	5.8	8.0	24	70	120	175	250	350	500
$zp_{\rm Vega}$																
$m_{\rm Vega}$	22.2	22.7	22.5	(22.0)	21.0	19.7										
$m_{\rm AB}$	24.5	24.5	23.4	23.4	22.8	22.5	22.1	19.7	20.0	18.5	13.5					
Flux	0.6	0.6	1.6	1.6	2.7	3.7	5.3	48	37.7	150	15	3.2	11.	19	20	17
Units	μJy	μJy	μJy	μJy	μJy	μJy	μJy	μJy	μJy	μJy	mJy	mJy	mJy	mJy	mJy	mJy

Table 3: Table of final depths expected over these fields. For SPIRE and PACS we quote estimates of the confusion limit which is a feasible limit to reach over these for the four longest wavelengths but probably only over a sub areas at 120 micron.