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 33 sq deg. of the southe fields in $u, g, r, i, z2$ to 10σ AB magnitude limits of $m_{\rm AB} =$ 25.8/26.0/24.9/25.0/25.0 respectively. We will detect roughly 2 million galaxies with a mean redshift of . From $0.5 < z < 2$ the survey volume in redshift slices of $\Delta z = 0.2$ is the same as that of SDSS and will be the high-z counterpart to SDSS.

This depth is sufficient to obtain broad band photometric redshifts to an accuracy of *% for all galaxies at $z \sim 1$ whose stellar mass exceeds 0.1 M_* (or $0.3M_*$ at z = 1.5 and M_* at z=2) (TBC). We will detect $> 90\%$ of all SWIRE galaxies, $> 80\%$ of them in g, r, i, z and $> 60\%$ in u. This data will provide a homogenous legacy for these fields – prefectly complementing the existing SWIRE, Galex, Radio and X-ray data, the contemporary UKIDSS data and the future Herschel data.

From the many applications of this data in this proposal we concentrate on these specific goals: Star-formation and the assembly of stellar mass; extreme objects; measuring galaxy clustering, bias and their evolution; identifying galaxy clusters and studying the evolution of their members; Unification schemes of Active galaxies and the connection between AGN and galaxy formation; weak lensing and its implications for cosmological parameter estimation.

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

2.1 Scientific rationale:

One of the key questions in Astrophysics and Physics in general is how did galaxies form and evolve. Serious questions remain unresolved such as the bias between galaxy and mass density fields; the role of environment in galaxy formation; the origin of bi-modalities between passive and actively star-forming galaxies today; the nature of sub-mm galaxies and their relation to Lyman-break galaxies etc.

While struggling to explain key results at low and high redshift, the only really viable physical models for galaxy formation are the hierarchical structure formation models. These make specific and relatively untested predictions of the clustering of star-forming and non-starforming galaxies at high redshift.

To resolve these open questions and test hiera to observe large samples of galaxies over large fields. We intend to submit a proposal to provide complete and homogeneous multi-wavelength optical coverage of the Southern and Equatorial SWIRE+DXS fields: ELAIS-S1 (3×3 deg = 9 sq. deg.: 00h 38.5m -44° 00′); SWIRE-CDFS (2×3 deg = 6 sq deg.: 03h 32.0m -28 °16′); XMM-LSS (3×3 deg = 9 sq deg. 02h 21.3m -04 ° 30′) and SA22/VIMOS-4 ($3 \times 3 = 9$ deg sq. deg 22h 17.8m +00° 24′).

Our primary aim is to study the full variety of galaxies, their evolution and clustering from $0.5 < z < 2.5$ the most active period in the Universe's evolution. The SWIRE-IRAC and UKIDSS (and we expect VISTA) data will provide the backbone of this census by allowing us to uniformly select galaxies on the basis of thei SWIRE-MIPS, SCUBA-2, radio and ultimately Herschel data at longer wavelength data probe the rest-frame Mid/FIR dust emission from these galaxies probing the star-formation and accretion activity.

A secondary goal is to use exploit this rich space of physical volume, cosmological time and multi-wavelength coverage to discover rare and exotic objects which will probe some of the most extreme short-lived, but still important, phases of galaxy formation.

The optical data of this proposal are an essential component to this census. (i) They will provide us with the photometric redshifts, without which all the component surveys are severely restricted. (ii) They enabe us to study the younger stellar populations, critical for tracing the origin of the blue/red bi-modality (iii) Allow us explore the morphology of different stellar components (iv) provide identifications for follow-up

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. It will also help fulfill ESO's commitment to support all Spitzer Legacy Programs with significant ESO involvement. Ultimately the data in these fields will provide a homogeneous multi-wavelength resource that will provide a view of the $z \sim 1$ Universe matching and exceeding the view SDSS+UKIDSS-LAS+WISE+ASTRO-F provide of the $z \sim 0$ Universe.

2.2 Hierarchical paradigm: Cedric Lacey, Carlos Frenk, Peter Thomas

The central plank of the hierarchical model of galaxy is that galaxies form in small units which coalese to form the galaxies we see today. Fundamental predictions of this model a be distributed in smaller systems at higher redshifts (ii) most star-formation should occur in small systems and presumably moderate star-formation rates (iii) galaxies should first form at the highest peaks in the density field which will be more clustered * i.e. specific predictions for galaxy bias* (iv) clusters should have formed by a given redshift *?*?. The VST CEnsus proposal will enable us to test all of these predictions....

2.3 Star formation & the Assembly of stellar mass

Goals: An accurate census of the full multi-wavelength properties of typical galaxies $z < 2$. To quantify the chronological history of star-formation; the proportion of stars formed in as a function of star-formation activity (active/quessent phases); star-formation rates as a function of stellar mass and its evolution. SFR and Stellar-mass distributions as functions of different galaxy types (e.g. morphologies); Evolution of correlations between star-formation tracers.

Methods: Luminosity functions in bands that probe starformation, UV, U, FIR, Radio. LFS caculated using photo-z and inversion techniques. Luminosity functions in bands that probe stellar mass, r, J,k, 3.5μ. Bi-variate Luminosity functions to explore SFR vs Stellar mass. Rest-frame Colour vs magnitude plots. Measuring halo occupation fractions.

Driving Requirements: Depth to reach high redshift. Multiple optical bands and good SNR to provide good broad-band photo-z. Large area to provide very large statistical samples to explore subtelties in shape of LFs, LFs in many sub-classes. Large area to provide sufficient galaxies in high-luminosity classes. Well studied fields at UV, IR and Radio wavelengths to provide different SFR tracers. Good imaging for morphology.

Follow-up: Redshift surveys with multi-object spectrgraphs to calibrate photo-z.

To understand galaxy evolution we have to compare the statisical properties of galaxies in the past with those today. SDSS and 2dFGRS have had a dramatic impact on the level of our understanding of the local Universe. Large statistical samples in many wavelengths have revolutionised the precision with which we can hope to understand galaxy populations. We need now need to obtain similar samples at $z \sim 1-2$.

2.3.1 Star formation: Michael Rowan-Robinson, Kevin Xu, Marie Trayer, Carlotta Gruppioni

2.3.2 Assembly of Stellar mass: Jon Loveday, Alberto Franceschini

2.3.3 Bi-modalities and Bi-variate luminosity functions: Eric Bell, Payam Davoodi, Francesca Pozzi

2.4 Extremely high star-formation rate systems and extremely massive galaxies: Duncan Farrah, Carol Lonsdale, Ian Smail

Goals: What are the upper bounds on star-formation activity? Are Luminous Infrared galaxies the transition objects from blue to red galaxies? What are the most massive galaxies at each epoch. How many massive galaxies exist at high redshifts?

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 assement of number densities.

Follow-up: Deep imaging from ground and Space Telescopes. NIR and Optical spectroscopic Follow-up on 8-m class telescopes.

Extreme objects Luminous infrared galaxies are locally rare and energetically insiginificant (*IRAS*). At higher redshifts they apparently become more significant (*SCUBA*).

2.5 Clustering: Seb Oliver, Eduardo Gonzalez-Solares, Peter Thomas, Serena Bertone

Goals: To test gravitation instability picture and theories of biased galaxy formation.

Methods: Slice survey volume in photo-z slices. $w(\theta)$ in each slice. Inversion via Limber's equation. Allows us to determined the $\xi(r)$ on scales $r > *$ (*determined by photo-z errors*) and its evolution.

Requirements: Large-area - 3 deg is $\sim 100h^{-1}$ Mpc at $z \sim 1$. Large numbers of galaxies - good statistics. Deepth to esnure we probe typical galaxies, reprenstative of stellar mass, i.e. L_*

Follow-up: Redshift surveys to obtain accurate $N(z)$ for each slice from spectra-z.

2.6 Clusters: **Ian Waddington, Alastair Edge, Richard Bower, Kathy Romer**

Goal: Evolution of galaxy populations within clusters. Abundance of clusters and cosmological parameter estimation.

Method: Identify clusters with variants of red-sequence method. Identify populations within clusters.

Requirements: Large area - one rich cluster pe

Follow-up: Ground & space-based imaging of cluster candidates. Multi-object spectroscopy of cluster members.

Galaxies form first in clusters thus at a given epoch clusters provide the most dated archelogical remains and deepest probe of the earlier Universe.

2.7 AGN: **Evanthia Hatziminaoglou, Richard McMahon, Gene Smith, Brian Siana, Mari Polleta Andy Lawrence, Ismael Perez-Fournon**

Goals: Detailed exploration of AGN unification schemes. 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 AGN LFs.

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.

Follow-up: AGN candidates to be followed up with redshift surveys on 8m class multi-object spectrographs.

AGN and galaxy evolution appear to be related, e.g. ULIRGs, similar luminosity density evolutions.

2.8 Lensing: **Andy Taylor, David Bacon**

Goals: Determine dark matter field to estimate cosmological parameters.

Method: Weak-lensing from shear etc. Photo-z

Requirements: Deep imaging with high quality images. Photo-z for distribution of lensed galaxies. Large Area.

2.9 Immediate objective:

- provide optical (r) identifications fo
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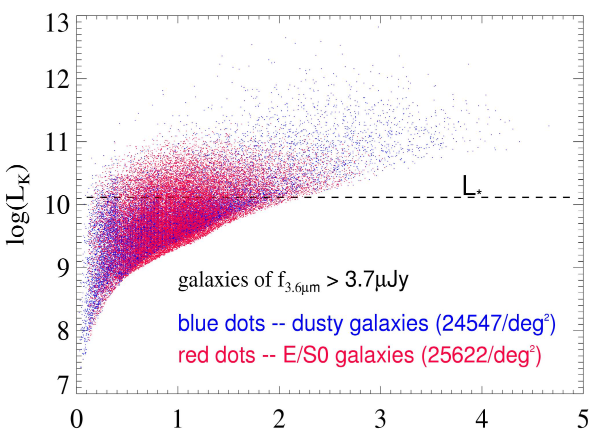
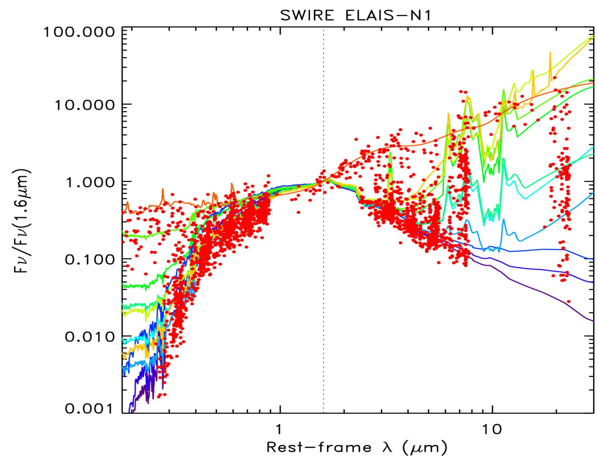
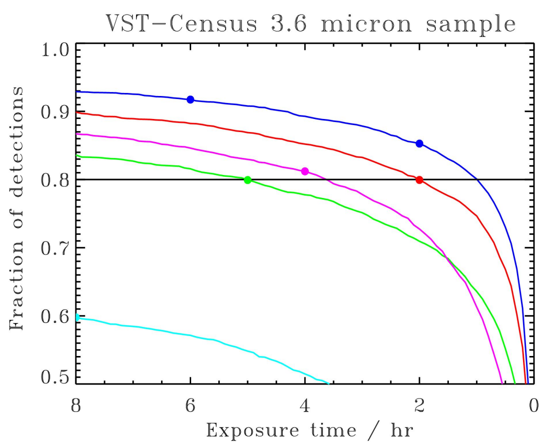
- morphologies for $*$ of galaxies
- provide photo-z estimates with an accu

2.10 Figures







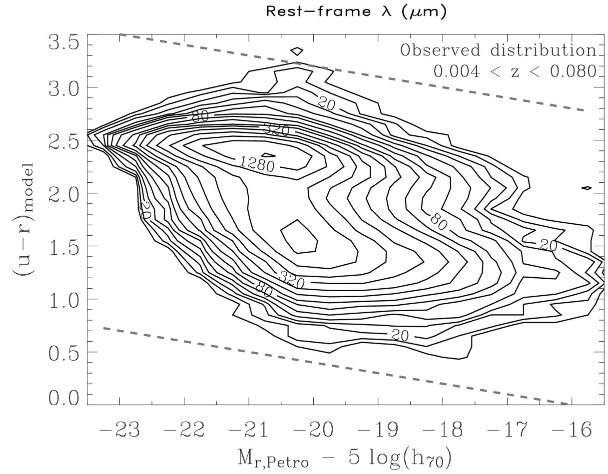


Figure 1: K-band Luminosity redshift plane for galaxies targeted in this proposal. This shows the very complete coverage of the stellar mass to high redshift. Calculated from a simulated catalogue from the models of Kevin Xu [?] flux limited at the SWIRE 3.6μm limit, 5μJy

Figure 2: 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.

Figure 3: Detection fraction as a function of exposure time: u-cyan; g-green, r-red; i-blue, z-magenta. This clearly shows that i is the most efficient for detecting SWIRE sources and thus for detecting stellar mass and star-formation. We have demanded that we have a minimum of 80% id fraction in u, g, r and each epoch of i and a 60% id fraction for u and > 90% id fraction from the combined three epochs of i. Identification fractions are from simulated SWIRE catalogues using the model of Xu et al. [?], updated for first Spitzer results and are tabulated in 2

Figure 4: TO BE REPLACED. Bi-modailty from Census data vs z

Figure 5: TO BE DONE. Redshift Distribution $N(z)$

Figure 6: TO BE DONE. Photo-z vs spectra-z

Figure 7: TO BE DONE. Volume VST vs SDSS

Figure 8: TO BE DONE. Recovery of LFs using photo-z

Figure 9: TO BE DONE. Evolution of correlation function with redshift and recovery

Figure 10: TO BE DONE. Example extreme objects

Figure 11: TO BE DONE. Something for clusters

Figure 12: TO BE DONE. Something for AGN

Figure 13: TO BE DONE. Something for Lensing

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

3.1 VST-16

q.v. broad band and medium band photo-z and depth. VST-16 requires VST-Census for good photo-z. Largest areas and faintest samples requires broad band IDs and photo-z.

3.2 CFHTLS

Our survey covers fields that are missed by CFHTLS, yet have very valuable ancillary data (esp. Spitzer/UKIRT data). It is essential that we cover the XMM-LSS field even thought it is covered by CFHTLS to provide a homogeneous legacy product, this is essential for uniform photo-z calibration.

4 Observing strategy: (1 page max)

Survey homogeneity of exposure and calibration is vital for good photometric redshift and to maximise legacy. Though *Jitter* mode provides uniform coverage it does not allow for chip-chip variations or to use chip-chip cross-calibration. We thus opt for *Dither* mode, maximising the number of frames per pointing, 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. We recognise that some science goals require complete single-band identifcation 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: *Dither*. Minimum of 16 frames per pointing (some split over nights).
- Observing Strategy: *Deep*. Splitting long total exposures over nights, observing conditions and also semesters.
- Observing Strategy: *Mosaic*. Smallest field (CDFS) will be 2×3 pointings, all others will be 3×3. Pointings will overlap to allow for quality control and calibration.
- Standards: begining, 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/variablity 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	225	00h39m	dark/grey	1	clear	3×3
SWIRE-CDFS	150	03h32m	dark/grey	1	clear	2×3
XMM-LSS	225	02h21m	dark/grey	1	clear	3×3
SA22/VIMOS-4	225	22h18m	dark/grey	1	clear	3×3

Table 1: Fields and conditions

5.1 Time justification: (1 page max)

We assume the filter zeropoints and exposure times based on

$$m_{\rm Vega} = -2.5\log\left(\frac{f_\nu}{\rm Jy}\right) + zp_{\rm Vega} \quad (1)$$

$$\log_{10}\left(\frac{t_{\rm exp}}{\rm hr}\right) = 0.8\times(m_{\rm AB} - zp_{\rm exp}) \quad (2)$$

	OmegaCAM				
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	2	6(2)	4
$t_{\rm frame}$ /min	15	15	7.5	7.5	15
$N_{\rm frame}$	32	20	16	48(16)	16
$m_{\rm Vega}$	24.8	26.1	24.8	24.6(24.0)	23.0
$m_{\rm AB}$	25.8	26.0	24.9	25.0(24.4)	25.0
Flux/ μJy	0.18	0.14	0.39	0.36(0.62)	1.4
% ID all	60	80	80	92(85)	81
% ID spiral	67	83	82	92(86)	82
% ID ellipticals	30	65	71	91 (80)	78

Table 2: Parameters for this survey. The three sections indicate: assumptions; definition of the survey and scientific consequences/drivers. Zero points are defined in Equations **??**. Exposure time zero points are determined using the 10σ, 10,000s limits given on the OmegeCAM WWW site http://www.astro.rug.nl/õmegacam/documents/p in parenthesies 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 3

The requirements to map a number of fields of $\sim 3\times 3$ degrees or $100h^{-1}$Mpc at $z\sim 1$ is set by (a) the need to measure clustering on scales around the linear/non-linear in different redshift slices (b) the need to provide a fair sample of the Universe, i.e. avoid sampling variance (c) the need to sample a wide variety of environments, including rare rich clusters (d) the need to maximize the discovery space for rare objects.

It is well known that the rest-frame NIR bands are very sensitive to stellar mass and insensitive to e.g. star-formation or AGN activity. The SWIRE 3.6 μm band is thus ideal for probing stellar mass. E.g. at $z = 1.5$ SWIRE probes to 1.3 mags below L_* in rest-frame NIR and thus detect 70% of the total NIR light emitted by all galaxies and thus detect the same fraction of all stars.

Our optical depth requirements will be to detect at least 90% of spirals and 90% of ellipticals/spheroids in at least one band and to detect more than 80% of all sources in 4 bands and > 60% of all sources in the u-band. To test this we have used simulated catalogues from Kevin Xu, results are summarised in Table **??**. 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 85% of all sources. The exposures we have chosen fullfil the above requirements. N.B. that for Spirals we will detect 67% of sources in u and thus presumably in 5-bands.

The total is 25 hours per pointing. With a total area of 33 sq. deg. this amounts to 825 hours in all or 103 (clear) nights, excluding overheads.

6 Data management plan: (3 pages max)

6.1 Team members:

Name	Function	Affiliation	Country

6.2 Detailed responsibilities of the team:

The team is divided into * working groups. Each person is primarily associated with one working group though some may make smaller contributions to a second group.

6.2.1 Observation Planning

The observation plan will be constructed by the Data Processing and Quality control teams.

6.2.2 Data Processing

The data processing team is divided between CASU and IPAC. CASU will process the raw data and associated calibration data to single pointing maps and catalogues using the VISTA pipeline. IPAC will mosaic and stack the maps together using the Montage software used for the SWIRE data processing and using the same tile scheme that has been used for SWIRE. CASU will then re-extract sources from the stacked maps using the VISTA pipeline.

6.2.3 Quality Control

The Quality control team: Sussex, MPIA, Durham. They will validate the catalogues from the data processing pipeline. Matching sources deteceted in overlap regions, comparing and adjusting the calibration as required.

6.2.4 Modelling/Photo-z

The modelling and Photo-z team includes Sussex, Durham, IPAC, Imperial, Padova, UCSD. They will provide independent and concensus photometric essential for planning, quality control and .

6.2.5 Archiving

The archiving team is IPAC and IfA, Edinburgh.

IPAC will archive the data in IRSA (as has been done with the SWIRE data) and/or ASTRO-Grid will also ingest the data into the UKIDSS/VISTA archive.

6.3 Data reduction plan:

6.3.1 Data reduction pipe-line

6.4 Expected data products:

Different data producst will be released at each release (V1-V4)

- photometrically calibrated, single pointing maps (V1-V4)

- single-band catalogues (V1-V4)
- stacked maps (V2-V4)
- band-merged catalogues (V2-V4)
- single-band & band-merged catalogues from stacked maps (V3-V4)
- photo-z catalogues (V3-V4)
- mock catalogues (V3-V4)
- simulation tools for estimating full selection criteria (V4, 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. The final products will be released three years after the first cycle of observations have been completed.

- **T0: Spring 2006** First Epoch Obse
- **T0+9months:** Version 1 Maps/Catalogues released
- **T0+12months:** 2nd Epoch Observing
- **T0+18months:** Version 2 Maps/Catalogues released
- **T0+24months:** 3rd Epoch Observing
- **T0+27months:** Version 3 Maps/Catalogues released
- **T0+36months:** Final Maps/Catalogues released

7 Envisaged follow-up: (1 page max)

Spitzer data have now been taken in XMM and CDFS, S1 is expected in December. We expect that a case can be made to Spitzer to attempt to match the SWIRE-IRAC observations in the SA22/VIMOS-4 field. ATCA observations covering 6 sq. degees 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. 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.

Inst.	GALEX	WFCAM			IRAC				MIPS		PACS		SPIRE		
band		J	H	K	1	2	3	4	24	70					
λ/μm		1.	1.6	2.2	3.6	4.5	5.8	8.0	24	70	120	175	250	350	500
$zp_{\rm Vega}$															
$m_{\rm Vega}$		22.5	(22.0)	21.0	19.7										
$m_{\rm AB}$		23.4	23.4	22.8	22.5	22.1	19.7	20.0	18.5	13.5					
Flux		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	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.

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

This proposal will help fullfil 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 fo 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 approp 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 but has had very little support from ESO to date.