The CFHTLS-Deep survey

3.1. Summary of Deep observations

3.1.1. Presentation of the survey

The CFHTLS-Deep component of the survey is strongly linked to the SNLS program and shares the same data. The main scientific driver is the determination of the cosmic equation of state, deduced from the supernovae measurements, so the observational constraints of this part of the CFHT Legacy Survey are dominated by those of the SNLS: multi-color observations in g', r', i' and z', with regular sequences every 3 to 4 nights. However, the CFHTLS-Deep survey, corresponding to the stacks of all the acquired data, is another direct output of the SNLS program. In order to highlight its scientific rewards, the wavelength coverage was extended to the u* band at similar depth than in the other bands. These observations correspond to the only part of the Deep survey observed independently from the SNLS (therefore with no time constraints).

Obviously the scientific outputs of such a Deep survey will start to be more and more competitive while the survey goes on. Presently, with 1.5 year of observations, 2 fields (D1 and D4) were observed for 2 seasons while the two others (D2 and D3) were observed only for one period, making the present limiting magnitudes not very competitive compared to other existing surveys. In addition, the first official stacks were released in November 2004, only 4 months ago. However the detailed performances achieved and measured in these stacks are within the expected ones. The choice of the 4 Deep fields has revealed very successful with many follow-ups in progress which are detailed in this report.

On the operational point of view, the data acquisition is relatively smooth although the lower than expected efficiency of the survey reduces the magnitude depths of the stacks. In practice, all the SNLS data are put forward with strong priority, because of the time constraints, so 4 out of the 5 filters are observed regularly at relatively high speed. *The drawback is that although the u* observations do not require such constraints, there are real difficulties to get these observations done at a similar speed: they have systematically less priority that the other components of the CFHTLS, once the main SNLS observations are done.* The present results from the Deep clearly demonstrate this limitation. It was partly recovered during last semester for the fields D1 and D4, but it remains the main concern of the coordinator of the Deep survey, and of the Steering Group. The scientific consequences of a poor filter balance on the achievement of the scientific goals are also discussed in the report.

3.1.2. Scientific goals

A short reminder of the main scientific goals of the Deep survey is presented. First the size of the field of view is one of the largest for which very deep ground-based observations are foreseen. Multi-color energy distributions (SEDs) of faint galaxies will be drawn for any type and any redshift, allowing a detailed and comprehensive mapping of large scale structures up to the highest redshifts. Galaxy formation and evolution models within the CDM paradigm are presently mature enough to propose a large number of predictions on the distribution of high redshift galaxies in terms of mass and luminosity: luminosity function, bias factor, clustering and correlation functions, properties of the galaxies versus their environment, etc... The deepest multi-color datasets obtained so far are the Hubble Deep Fields (North and South) and the ACS Ultra-Deep field. Although they cover a very small angular area, they have lead a large number of investigations of prime interest, like the identification of the very high redshift population of dropouts galaxies at redshifts up to 5-6 or the optical identification of galaxies selected either in the X-rays or in the far-IR/submm domain. Similar approaches are foreseen in order to scientifically exploit the CFHTLS-Deep survey, taking advantage of the large area covered at high magnitude. In particular, all studies concerning the environment of the galaxies or their spatial distribution are possible up to scales of several Megaparsecs at z=1. Using mostly photometric redshift techniques on large samples of very faint and distant galaxies, all the physical properties of the galaxies (like the Star Formation Rate, the absolute magnitude or the stellar mass, the spectral type and the stellar content, the morphology ...) can be studied globally or on very large scales. Several issues can be addressed with high accuracy and details with this kind of sample, like the evolution of the cosmic SFR versus the spectral types of the galaxies, the mass assembly history of the galaxies in different environments, the evolution of the morphological types fractions with redshift, etc ... All these global properties will be easily compared with the general predictions of the cosmological models (CDM framework for example).

The 4 CFHTLS-Deep fields were selected for different reasons, leading to different status regarding the scientific exploitation of the multi-color data.

- ✔ D1 (RA=2h) is centered on the Deep field of the VVDS (VLT/VIRMOS Deep Survey), a spectroscopic survey running at the VLT (PI= O. Le Fevre, Marseille). 13000 spectra are presently acquired, with 11000 secure spectroscopic measurements and the release of this sample is foreseen for the beginning of 2006. The sample is complete up to I_AB=24 and the median redshift is 0.76. A preliminary analysis of the spectroscopic redshift versus the photometric redshift has been attempted from this sample, independently by two members of the VVDS team (R. Pello and S. Arnouts, see below). The complementarity between the deep spectroscopic sample and the ultra-deep photometric sample of the CFHTLS will be exploited as the loss in redshift accuracy for the photometric sample will be largely compensated by the statistical increase in object numbers from I_AB=24 to I_AB=26. Evolution of the galaxy luminosity function up to high redshifts will be drawn 2 magnitudes deeper than with spectroscopic samples, allowing to address a much smaller mass range, more sensitive to the initial processes of mass assembly of dark matter halos. In addition, the individual properties of galaxies will be studied versus their environment, using both accurate estimators of the local density and spectroscopic information for the brightest galaxies.

- ✔ D2 (RA=10h) is centered on the COSMOS field. COSMOS is an HST Treasury Project to survey 2 square degrees on the sky with the ACS, and includes several multi-wavelength follow-ups (XMM, VLA, VLT for the spectroscopic follow-up and Subaru+CFHT for the multi-color deep imaging). Most of these data will be publicly available very rapidly, increasing the amount of observational data over this field of view. Concerning the CFHTLS-Deep, at the end of the survey, D2 imaging will reach limiting depths significantly deeper than the Subaru data, although present data are not fully competitive (only one period of observations). However, the fact that HST data are already publicly available over the central region of the COSMOS field (fully covering D2) makes subsequent studies very promising for the CFHTLS community. As an example, the HST imaging of all the galaxy hosts of the supernovae detected in D2 will allow a more detailed analysis of the morphological properties of these galaxy hosts, coupled with a multi-color SED analysis from the CFHTLS data (S. Basa & G. Soucail)

- ✔ D3 (alpha=14h) is centered on the Extended Groth Strip region of the sky. Several follow-ups are in progress, especially the "Deep2" survey aimed at studying a sample of thousands of galaxies with redshift larger than 0.7, using the DEIMOS spectrograph at Keck. Existing collaborations, mainly on the Canadian side (L. Simard, D. Schade) are ongoing, especially on the morphological characterization of the galaxies related to their environment.

- ✔ D4 (alpha=22h) is centered on the quasar LBQS2212-17, deeply observed with XMM. No spectroscopic surveys are foreseen presently, although some collaborations are in progress to benefit from the deep XMM pointing available in the archive. In addition D4 has been observed with GALEX within its first year of operation and data are publicly available within the first GALEX data release (GR1).

Other multi-wavelength follow-ups are in progress and start to be exploited: in continuation of the DIS (Deep Imaging Survey) GALEX will visit entirely the 4 CFHTLS-Deep fields before the end of the year 2005, and the joint analysis of both data-sets is in progress in the GALEX team in Marseille. Similar works will be done with SPITZER within the SWIRE survey which will cover a field of view larger than D1 and partly embedded in W1.

In summary, the choice of the 4 Deep fields appears very satisfactory as it raises several multi-wavelengths or spectroscopic follow-ups with several groups involved in these follow-ups. Each field reveals its specificity and the community is actively taking advantage of it for exploiting the data.

3.1.3. Present status of the survey and operational issues

Filter distribution

There are several ways to compute the integration time spent on one field, so we remind the conditions of validation for the Deep survey: data validated by the QSO observers with quality flag between 1 and 2, a seeing limit of 0.9" measured on the central ring of CCDs, except in u* where the limit is released to 1.1". At the end of the observing period 2004B, 232 hours of integration time were acquired for the Deep survey since the official start of the CFHTLS (May 30th, 2003). The summary of the filter distribution for each field is displayed in Figure 1. Only pure integration time is accounted for, which does not take into account the

40sec/exposure readout time. Compared to the total allocation of the survey, this reduces by 10% the amount of time truly useful for the Deep.

From the Deep survey point of view, the filter balance resulting from the present observational strategy is not fully optimal and the influence of the lower than expected efficiency of observations is clearly visible in Figure 1: because of the importance of getting well sampled light curves of supernovae, the top priority observations (i' and r') are usually favored in the course of an observing run, especially when the weather is poor. g' observations are more difficult to get in good seeing conditions (and away from the Moon) and u* ones, which are not time constrained, are most of the time postponed once the observations for the SNLS are done and while Wide and Very Wide sequences are pending.

To overcome this well identified difficulty, the Steering Group has taken the opportunity to push u* observations of D1 during the last October and November runs (2004B), thanks to additional observing time allocated by the Board to the survey. This resulted in an increase of u* observations by 6 hours, allowing a much better balance compared with i' on D1. D4 also appears well balanced: this is understood because it is located at an RA of 22 hours and the overall pressure in this part of the sky is smaller at CFHT. Moreover there is no competition with the Wide survey which does not provide a W4 field.

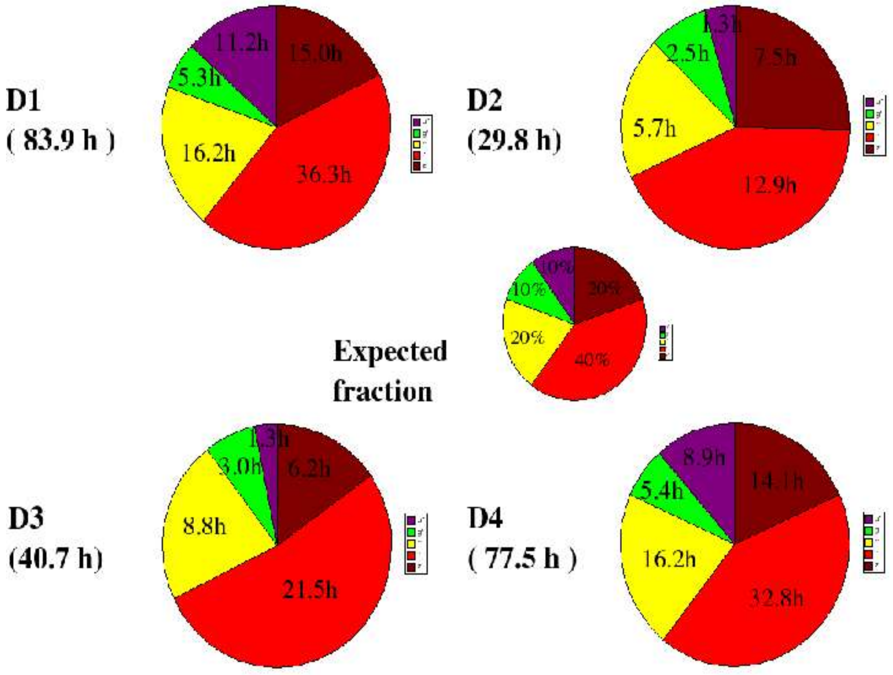

***Figure 1**: Distribution of validated data acquired for the Deep survey up to the end of semester 2004B.*

D2 (COSMOS field) and D3 (RA=14h) suffer much more from the competition with both the Wide survey (from W2 at 9h and W3 around D3) and other PI programs from either the French/Canadian agencies or others. In order to partly solve this issue for the forthcoming semester (2005A), the Steering Group has taken two actions: the u* observations of D2 are postponed, considering that the deep u* data taken by the COSMOS collaboration on the UH time with MegaPrime will be publicly available rapidly and therefore could be added to the stacks of the CFHTLS. For D3, u* observations will be reduced to a minimum, considering the present low efficiency of the CFHT queue. If this tendency is not reversed rapidly and if the deficit in u* observations is not compensated in the next year or so to get the correct filter balance, a significant part of the scientific outputs of the Deep survey will not be achieved: u*-dropouts and the study of the Universe at z=3 will be dropped, the quality of the photometric redshifts for faint objects classification will be reduced and many biases will be introduced in the redshift distributions, with an increase of catastrophic identifications in some specific redshift ranges ... It is hoped that it will be reversed rapidly and that the deficit in u* observations will be compensated in the next years in order to get the correct filter balance at the end of the survey.

For illustration, the following tables present the amount of observing time that would be necessary to add to what has been already observed in order to get the nominal fraction of time for each filter. This is computed with respect to i' observations, which are systematically "in advance" compared to the other filters. This already corresponds to more than 5 nights of observation, only to compensate for this effect!

	D1: i'= 36.3h			**D2: i'= 12.9h**			**D3: i'= 21.5h**			**D4: i'= 32.8h**		
	expected	**acquired**	**Diff**	**exp.**	**acq.**	**Diff**	**exp.**	**acq.**	**Diff**	**exp.**	**acq.**	**Diff**
u*	9.1	11.2	-2.1	3.2	1.3	1.9	5.4	1.3	4.1	8.2	8.9	-0.7
g'	9.1	5.3	3.8	3.2	2.5	0.7	5.4	0.3	1.4	8.2	5.4	2.8
r'	18.2	16.2	2.0	6.5	5.7	0.8	10.8	8.8	2.0	16.4	16.2	0.2
z'	18.2	15.0	3.2	6.5	7.5	-1.0	10.8	6.2	4.6	16.4	14.1	2.3

The uniformity of the total integration time with respect to filters is the strongest requirement of the Deep. In order to be correctly fulfilled, this will require additional observation time over the next semesters for compensation. The Steering Group also strongly encourages the Canadian and French TACs to be extremely careful in allocating additional observing time in RA bands when the load from the CFHTLS is high. Conflicts with PI programs tend to disfavor the CFHTLS considered as a single agency, although the science merits between a large Legacy survey and individual PI programs are never compared.

Influence of the seeing quality

The deficit of good seeing observations (IQ<0.9") is another issue which significantly reduces the efficiency of the survey. In the Board resolution, 194 nights were allocated to the

Deep/SNLS part of the survey with IQ<0.9" plus 8 additional ones with seeing above this limit. In fact, more then 15% of the data are acquired out of the seeing limit, partly because of the importance of the time constraints. The SNLS accepts to increase the IQ limit for the first and last observations of a run, considered as critical data points for a good fit of the SN light curves. These data are of no use then for the Deep stacks which impose a stringent cut in image quality. The reddest bands which are less sensitive to seeing fluctuations are less affected but this is crucial for g' observations, often more difficult to acquire with an IQ below the nominal limit. Presently, only 67% of the Deep-g' data have IQ<0.9" while this ratio increases up to 88% in z', still below the limit corresponding to the Board allocation. The effect is clearly visible in the Deep stacks released in T001: the u* and g' images have both a measured FWHM close to or above 1.0". More quantitatively, if we follow the prescriptions of the Megacam exposure time calculator (DIET), the S/N ratio of a point source is optimized when computed in an aperture of 1.45xFWHM diameter. Therefore for the same S/N ratio, the magnitude limit goes like -2.5log(FWHM/√T). At first glance, an increase of the seeing from 0.9 to 1.0" will correspond to an increase of 20% of the integration time to reach the same limit, or a reduction of 0.1 in the magnitude limit for the same integration time. The quantitative effect of this increase of IQ in the stacks could also be characterized by comparing the deep stacks with shallower ones selected with a reduced IQ limit. This work is in progress and will be quantified with the next release T0002.

Expected performances

Taking the data from D1, one can compute the limiting magnitude of a point source detected at 5σ within an aperture of 1.45 x FWHM, which is the standard defined by the MegaCam exposure time calculator (DIET) and which appears on the Web pages of the CFHTLS in terms of performances. Compared to the expected limiting magnitudes derived from the measurement of the average sky background in the same dataset, they agree within 0.1 magnitude and confirm the quality of the deep stacks in terms of magnitude performances.

Table 1: magnitude performances of the D1 stack
from the T0001 release

T0001 release on D1	u*	g'	r'	i'	z'
Exp. time	3h	2h	9h	14h	3.4h
FWHM	1.15"	0.98"	0.87"	0.88"	0.86"
Expected limiting mag.	26.8	26.8	27.2	26.9	25.3
Measured limiting mag.	26.8	26.9	27.1	26.9	25.2

The lower efficiency of the survey compared to what was expected initially has some consequences on the Deep survey. Presently, after 3 semesters of operation, the total integration time is 232 hours within the seeing limits and 293 hours in total. In nominal conditions it should have been 390 hours, so the reduction is roughly 40% for the IQ<0.9" conditions or a reduction of 0.3 magnitudes in the detection limit. This reduces the number of objects in the catalogs by 30 to 40% (depending on the slope of the number counts) and affects primarily the high redshift galaxies which fraction strongly increases with magnitude depth and the detection of all dropouts galaxies, preventing the analysis of this kind of very high redshift galaxies. This is mainly significant on the first release T0001 and will be attenuated as soon as T0002 is available.

Operation plan for the next semesters

It will follow the SNLS observations and try to insert u* observations as much as possible. The minimum requirement is therefore to get a significant amount of u* data very soon (within the next year) and then delay slightly the rest of the observations, possibly after the official end of the survey and during an extension after 2008. In practice, the following plan is proposed, in accordance with the Steering Group and compatible with the other components of the CFHTLS. It considers that up to the end of 2005A, 26h of integration time will be acquired in u*. During the following semesters, the goal is to add 2/3 of what should have been requested in nominal conditions (6.5h/field/year), i.e. 13h per field in 3 years. The rest will be proposed during an extension of the CFHTLS over 2 years, with a detailed scientific justification.

semester	**hours**	**comments**
2005B	18h	*try to get a total of 15h/field in u* ASAP*
2006A	18h	*idem*
2006B	4h	
2007A	4h	
2007B	4h	
2008A	4h	end of the CFHTLS
2008B	20h	extension of the survey...
2009A	20h	
2009B	20h	
2010A	20h	

Note that this is a *minimal* plan for the forthcoming runs. It will be modified if CFHT increases its efficiency as most u* observations are in B-priority. Any gain in efficiency will be directly applied in the B-queue.

3.2. High redshift galaxies

3.2.1. Preliminary results on photometric redshifts distributions

(R. Pello, F. Ienna, OMP Toulouse)

A crude and direct test of the photometric redshift performances of the CFHTLS-Deep was performed with the *HyperZ* software by R. Pello and F. Ienna (PhD Sutdent). Two spectroscopic independent samples were used to perform a blind comparison with photometric redshifts: first, the VVDS-Deep sample of 3860 galaxy spectra over the D1 field, and the Deep collaboration publicly available sample of 314 galaxies in D3. Results in the z=0-2 domain are presented in Figures 2 and 3 respectively.

The results are very encouraging at this stage, i.e. without any adjustment of the photometric zero points or the spectroscopic galaxy templates, there is only a small systematic shift ranging from dz~0.03 to 0.07, and a typical dispersion sigma(z) ~ 0.14-0.16 over the whole redshift domain, all the galaxy types and spectroscopic quality taken together for this exercise. The dispersion is smaller at z<1 for all galaxy types (sigma(z)~0.11), and even better (sigma (z)~0.06-0.10) for all galaxy types except young starbursts, as clearly shown in Fig. 2. The small systematic shift observed in both fields is not seen when performing the same analysis on simulated catalogs issued from GalICS, with photometric errors tuned to reproduce the present values achieved in the Deep. It could be the signature of an offset in the magnitude zero point in 1 or 2 filters, by a few 0.01 magnitudes only, with respect to the reference filters used to compute photometric redshifts, or other systematics producing the same behavior. In summary, the quality of photometric redshifts derived at this stage is as good as expected for a simple SED fitting, and small systematics should be easily corrected in future studies. Any substantial improvement on the depth and homogeneity of the data will bring invaluable improvements in the photometric redshifts, for the benefit of their use for the very faint and distant galaxies.

Different prospective studies are on-going using photometric redshifts to constrain the relevant statistical properties of galaxies as a function of redshift and environment, taking advantage of the unique sample provided by the Deep Survey (redshift distributions for magnitude or color-limited samples, Luminosity Functions, color-magnitude relations, stellar masses, high-z star-formation density). Most of the tools used on spectroscopic samples can be easily adapted to photometric redshifts using a statistical approach, in particular for luminosity functions and local density estimators. In association with a Deep Near-IR Survey with WIRCAM, these data will provide a complete view of the galaxy mass-assembly process all the way from the local universe to z=4, and set strong constraints on the abundance of star-forming galaxies at redshifts above 7.

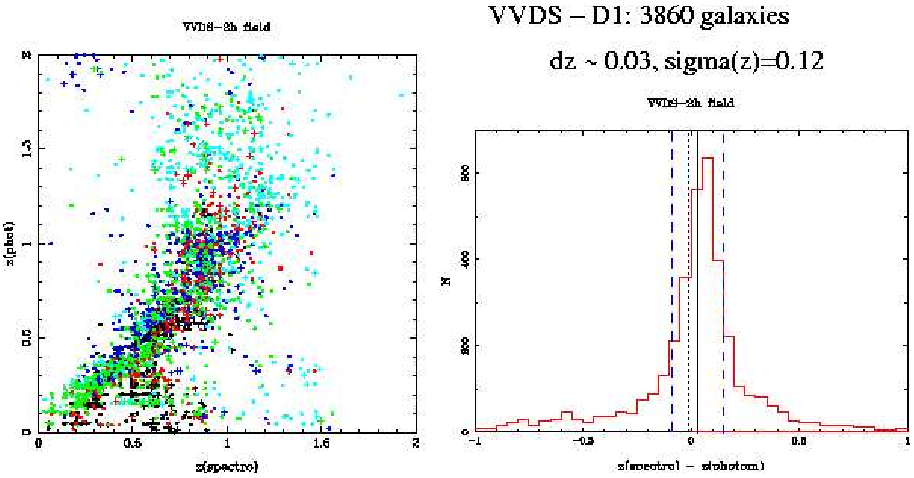

Figure 2: Blind comparison between spectroscopic and photometric redshifts at z=0-2, for galaxies in D1 and within the VVDS spectroscopic sample. Different galaxy types, based on a pure photometric SED-fitting classification, are identified in black(E/S0), red(Sbc), green (Scd), blue (Im) and cyan (young starbursts).

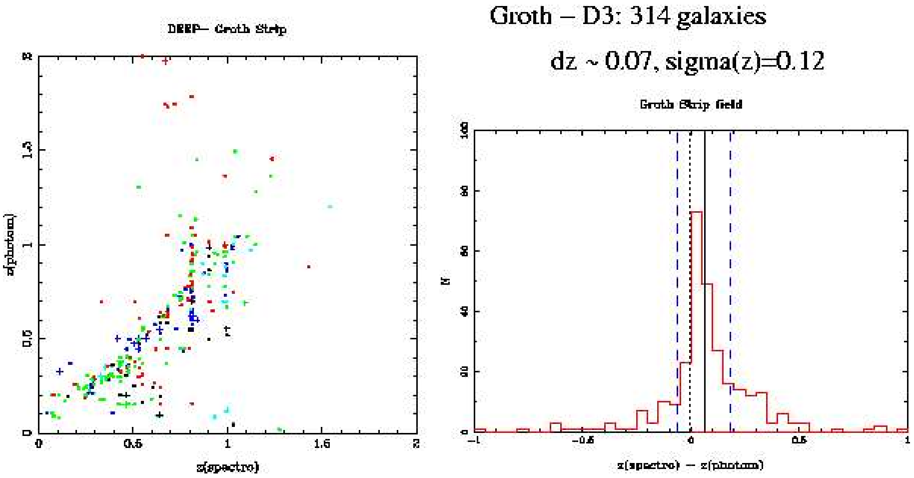

Figure 3: Comparison between spectroscopic and photometric redshifts for galaxies in D3 and within the Deep spectroscopic sample (Same comments as for Fig.2)

3.2.2. Galaxy Evolution in the CFHTLS Deep fields

D. Le Borgne, R. Carlberg (U. Toronto), H. Courtois, T. Sousbie, J. Devrient (Observatoire de Lyon), B. Rocca-Volmerange, V. de Lapparent (IAP)

A group of Canadian and French researchers is currently working on the inter-comparison of photometric catalogs derived from two independent data reduction pipelines: the Canadian SuperNova Legacy Survey pipeline, and the French Terapix pipeline. Systematic offsets, deep counts and completeness limits in the five filters are being compared and analyzed. Simultaneously, the photometric redshifts are estimated as well as their error bars in the four Deep fields with the code *Z-Peg* (Le Borgne & Rocca-Volmerange, 2002). This code takes advantage of the reliability of the synthetic spectral energy distributions modeled with the code *Pégase* (Fioc & Rocca-Volmerange, 1997). *Z-Peg* is being applied in parallel to both photometric catalogs. A preliminary comparison of the precisions obtained in each case is shown in Figure 4 for the D3 field. This figure presents the distributions of the error bars $\sigma(z)$ estimated on each galaxy, in two comparable samples ($i'<23.5$) derived from the two photometric catalogs. The median relative error $\sigma(z)/(1+z)$ is close to 0.07 in both cases, in good agreement with the overall performance of the code *Z-Peg*. The differences existing in the distributions of the errors can probably be related to differences in stacking strategies, but need more work to be understood. As side products, *Z-Peg* can also provide estimates of the ages of the galaxies, their metallicities, their stellar masses, and their dust content. The five photometric bands are necessary to obtain results concerning these quantities.

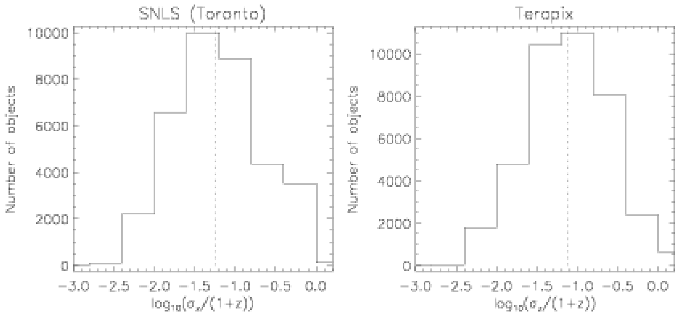

Figure 4: Distribution of the errors on photometric redshifts (measured with Z-Peg) in D3, for the two photometric catalogs provided by Terapix, and the SNLS pipeline, limited to $i'<23.5$. The median error $\sigma(z)/(1+z)$ is shown by a dotted vertical line.

In parallel, N-body simulations of the CFHTLS-Deep fields with various cosmologies are being developed in Lyon. The number counts and the spatial and angular 2 point correlation functions predicted by these models will then be compared to the values measured in the Deep fields. Several other developments are foreseen:

- The analysis of the selection biases coming from the different photometric pipelines will be done using these mock Deep Fields.
- The possibility of having at least two different cosmologies in the simulations will make it possible to trace the evolution of these number counts, and angular/spatial correlations. A noticeable difference between a dark energy as quintessence or a cosmological constant can only be seen at redshift $z\sim1$.
- Fast and robust codes for statistical analysis of very large datasets are presently developed within the *Horizon* French project. These codes are being tested on numerical simulations. The Deep fields provide a good test on a pencil beam survey at high-z. This geometry is quite difficult to take into account regarding the spatial 2-point correlation function. The photometric redshifts are essential to test the codes (in order to get through to the 3D set of galaxies in the pencil beam). The luminosity functions of galaxies in the Deep fields will also be investigated, using secure photometric redshifts and compared to the predictions from the simulations, in order to better constrain the N-body models.

This collaboration just began with the first public data release T0001. The mock CFHTLS Deep fields will be available during the year 2005. Important understandings of the cosmic distribution of galaxies will be reached with more integration time on the CFHTLS fields.

3.2.3. Lyman break galaxies and high redshift quasars

(J. Bergeron, A. Omont, IAP Paris – G. Soucail (OMP Toulouse) & N. Webb (CESR, Toulouse)

The number density of quasars at very high redshift is not well known. While the 2DF survey provides a good view of the QSO density and luminosity function up to z ~ 2, the best information on QSOs at z >~ 3 is presently afforded by the Sloan Digital Sky Survey (SDSS). The latter has provided the luminosity function (LF) down to M_1450~-25.5 at z ~ 4, and more recently has procured a breakthrough discovering QSOs up to z=6.4 and building a sample of nine QSOs with z > 5.7. The SDSS, however, is sensitive only to very luminous QSOs (M_1450 <~ -26.5) and provides no information about the faint end of the QSO luminosity function, which is particularly important to understand the interplay between the formation of galaxies and super-massive black holes. Deep multi-wavelength surveys like the CFHTLS-Deep or Wide can probe the luminosity function, the density and the nature of QSOs with fainter luminosity at z >~ 4, and especially in the highest redshift range - 5.5-6.5 - reachable with optical surveys. In addition, the recent X-ray and infrared surveys, combined with optical studies, have confirmed the importance and the richness of peculiar high-z QSO classes not well represented in classical catalogs of optical QSOs: in particular type II QSOs and red QSOs, significantly different of classical type I QSOs. All these distant quasars are usually selected by dropout techniques which can be applied on the CFHTLS-Deep, already with the present data. The z~3 objects are selected as u-band dropouts: the majority of the objects are Lyman Break Galaxies (LBGs), and the density of type II quasars is roughly 40 per square degrees. It drops to ~12 per square degrees at z~4 (g' dropouts). The building of a sample of type II (and type I) AGNs/QSOs at z>3.5 from the CFHTLS-Deep has started with the aim at studying the number density and luminosity function of the absorbed/obcured type II QSOs. The spectroscopic confirmation of the candidates will be proposed on the ESO/VLT in the forthcoming semesters.

Another project which is emerging is the multi-color identification of the X-ray sources detected in the very deep pointing done with XMM-Newton on the D4 field. Indeed this field was selected on purpose because of the existence of the deep X-rays pointing, and contacts are undergoing with A. Schwope and G. Lamer (AIP, Postdam, Germany) as members of the XMM Survey Science Center. They can provide a more detailed and reliable source list than the one existing in the XMM-Newton archives and this field is one of the deepest target observed so far with XMM. Most of the sources are expected to be faint quasars and already three extended sources coincident with clusters of galaxies or groups are identified. The broad diversity of source types in deep X-ray surveys will be studied thanks to an optical identification at magnitudes similar or deeper than to those attained in the Chandra Deep Field South, thanks to the depth of the D4 stacks. In particular, the optically faint X-ray sources (I>24-25) are mostly luminous obscured AGNs at redshift 1 to 4 (Brandt & Hasinger 2004, ARAA) and may represent a large fraction of the AGN population, especially in the faintest bins of the X-ray number counts and in the contribution to the X-ray extragalactic background. Further analysis in the near infrared is foreseen with WIRCAM in order to better identify this population of faint X-ray sources, especially the most obscured AGNs which should still be detectable in the J or Ks bands.

3.2.3. Galaxy morphology

(L. Simard, M. Nuyten, S. Gwyn, H. Rottgering, University of Victoria)

The size of the sample of galaxies from the Deep survey will soon be comparable to the SDSS sample, but extended to redshift 1. In addition the image quality (IQ ~ 0.8") is such that galaxy classification can be done in terms of Sersic parameter with high significance. And because the CFHTLS-Deep images are much deeper than HST images, the structural parameters of the disks (scale length, inclination and position angle) can be determined with similar accuracy than in HST images. Thanks to the spatial increase of the fitting area, these disks parameters are much better measured although the spatial resolution cannot compete with HST. In addition, the photometric redshift determinations are accurate enough to determine the local density around each galaxy and to study the environmental effects on the galaxy evolution. This work has already started at the University of Victoria (L. Simard, S. Gwyn), using some Deep stacks personally provided by S. Gwyn and a first paper has been submitted (Nuyten M., Simard, L., Gwyn S., Rottgering H., *The CFHT Legacy Survey: the morphology-density relation of galaxies out to z ~ 1,* submitted to ApJ Letters) .

3.3. Galaxy clustering

3.3.1. Measuring the clustering of distant galaxies with the CFHTLS

H. J. McCracken for TERAPIX and the VIRMOS consortium.

One of the key aspects of MegaCam is that it has relatively good response at bluer wavelengths, in contrast with previous wide field imagers at CFHT like UH8K and CFH12K. One key scientific topic using this unique capability is a detailed investigation of the properties of galaxies at z~3, the Lyman-break galaxy population. The current "state-of-art" study is that of Steidel et al, who covered 0.38 deg2 in 17 separate fields, selecting 2347 galaxies (half of which are spectroscopically confirmed). By contrast, a *single* Megacam stack has an effective area of ~0.88 deg2, and should contain around ~1000 z~3 galaxies to i'<24. Unfortunately, due to scheduling constraints, only a fraction of the total time allocated for the u* observations has actually been executed, and in each of the four fields the limiting magnitude in u* is well below what had been hoped for by this stage in the survey. The current u* stacks are not quite deep enough to detect Lyman-break galaxies at z~3, which requires depths of at least u~27 in order to reliably observe the passage of the Lyman break through the u* filter. However, the greater depth in the g' filter means that the CFHTLS Deep data can be used to search for galaxies at z~4 using the same principle as at redshift 3. Using model tracks generated by S. Charlot, we identified the approximate region in colour-colour space occupied by these galaxies. In both the D3 and D4 fields, we identified around ~500 z~4 candidate galaxies in each field. The number density of these galaxies is similar to those found by other workers at these depths. We measure an average amplitude of clustering over the two fields of log(A(1'))~-0.53, corresponding to r0 values of around ~10-15 h^{-1} Mpc (assuming a redshift distribution peaked at z~4). The interesting aspect of this work is that we find (at a high confidence level) that the slope of the galaxy correlation function is much steeper than the canonical δ~-0.8 value found for less luminous (and less massive) local galaxy populations. An interesting aspect of this measurement is that this "slope segregation" has already been observed locally by the SDSS and 2DF surveys, with early-type galaxies having a significantly steeper slope than late-types. An accurate measurement of the slope is only possible due large field of view of MegaCam. Finally, new u* observations, taken in November 2004, and to be included in the next TERAPIX data release, will extend the depth of the D1-u* stack by around ~0.6 magnitudes, and permit these studies to be carried out at z~3.

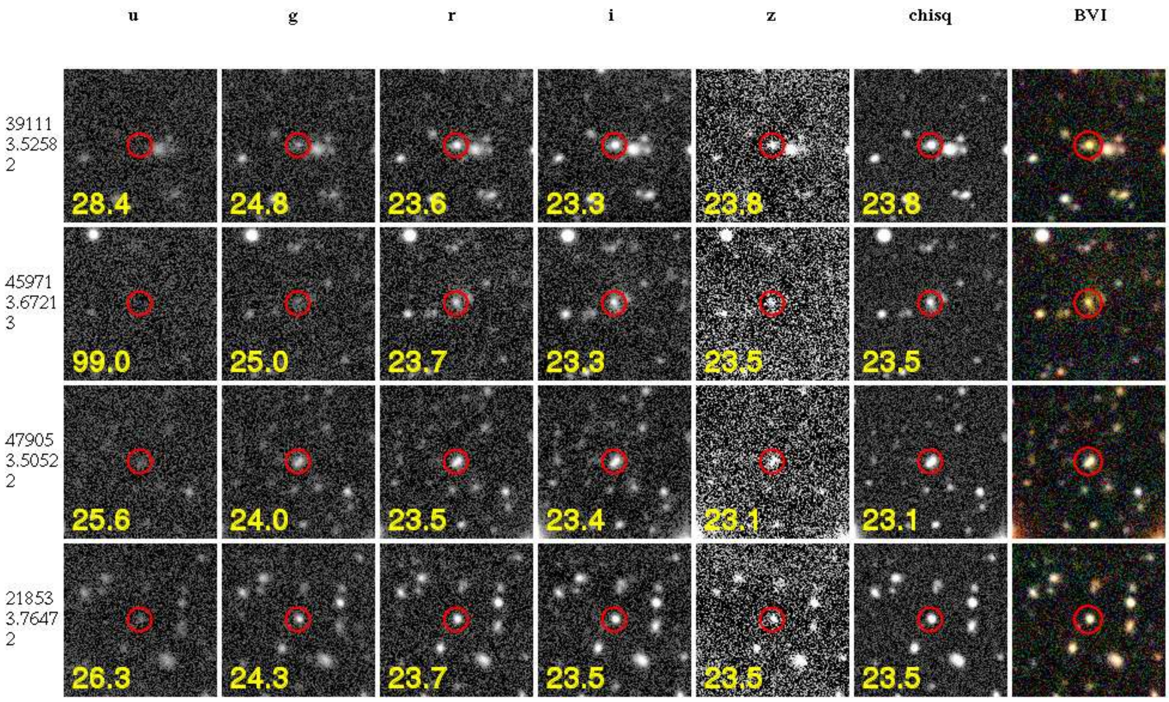

Figure 5: Selection of high redshift galaxies as seen in the CFHTLS-D1 field, at redshifts of 3 and above. Spectroscopic redshifts (on the left) were determined by the VVDS team.

We have also used the CFHTLS deep data to investigate the properties of galaxies at high redshift in the VIRMOS-VLT deep survey (VVDS; LeFevre et al); the D1 field covers the same region as the VIRMOS-VLT deep survey data (and even the relatively "shallow" CFHTLS u* data is around two or three magnitudes fainter than the ESO WFI data available to the VIRMOS consortium). Additionally, the D3 field also contains several hundred Lyman-break objects studied by Steidel and collaborators, in the "Westphal field" (the depth of the CFHTLS-u* images in this field is still very shallow unfortunately; a top priority of the survey in the coming months must be to increase the depth of u* stacks in this region). These datasets provide two complementary views of the Universe at high redshift: the VIRMOS sample is purely magnitude limited, whereas the Westphal field spectroscopic sample objects were pre-selected based on cuts in colour-colour space. Having a common magnitude system (the CFHTLS) greatly simplifies comparisons between the two datasets. The unique aspect of the CFHTLS/VVDS with respect to the Westphal data is that it provides a measurement of the bright end of the Lyman-break luminosity function. Present results indicate that previous surveys may have underestimated the luminosity density of Lyman-break galaxies at these bright magnitudes by up to a factor of two or more.

It is worth repeating, in conclusion, that one of the key objectives for the CFHTLS-Deep in the next year should be to increase the u-band integration times on fields D2, D3 and D4 so that reach at least the canonical 50% completeness levels of u~27.

3.3.2. The clustering of rest-frame UV selected galaxies at z∼1

(S. Heinis, B. Milliard, S. Arnouts, J. Blaizot, T. Udavari, B. Meneux, J. Donas, M. Treyer, H.J. McCraken, L. Tresse, Observatoire de Marseille)

The CFHTLS DEEP survey, with its five bands and unique coverage and depth, is of primary interest in the domain of galaxy evolution, because it gives access to the rest-frame UV continuum and thus to the star formation activity (modulo extinction), over a huge redshift range. In terms of star formation history, the CFHTLS u* band data fill the gap at intermediate redshifts between studies in the distant universe from the LBGs, and those achieved in the relatively nearby Universe from GALEX observations. All these studies are performed with the same technique, thus minimizing differential effects that hamper many evolutionary studies today.

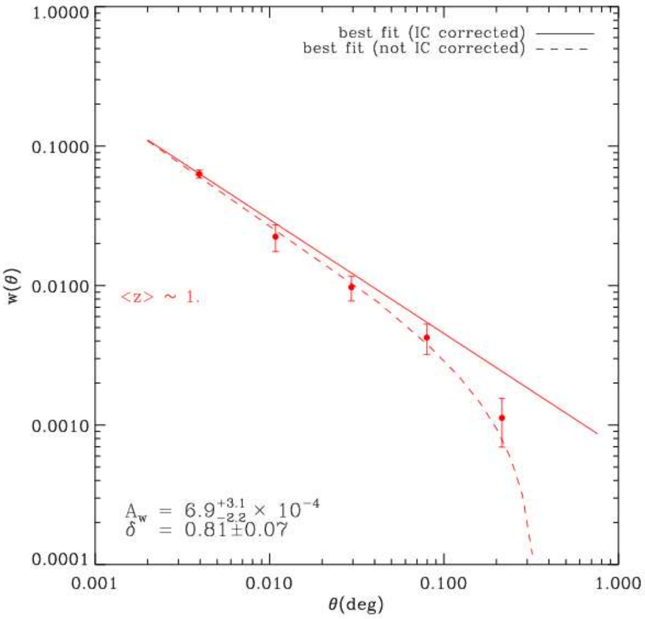

Figure 6: Angular correlation function averaged over the 4 Deep fields for galaxies with 20<u<24.5 corresponding to an average redshift <z> ~ 1.*

In the frame of an on-going study aimed at understanding the links between the evolution of star formation and that of the underlying matter, we have started to measure the evolution with time of the clustering of the star forming galaxies consistently selected in the rest-frame UV. In particular, we have used the u* band data in the 4 fields of the CFHTLS DEEP survey to perform a preliminary derivation of the angular correlation function near z~1 (Heinis, Milliard, Arnouts et al 2005, presented at the CFHTLS workshop on February 4th, 2005). The co-moving correlation length derived from a calibration of the z-distribution against VVDS spectroscopic redshifts is found close to 3 Mpc (Ω_m=0.3, Ω =0.7, h=0.7). When combined with the GALEX results in the local universe (Heinis et al 2005, AAS), and results in the distant universe (Giavalisco and Dickinson 2001, Adelberger et al. 2004) the CFHTLS DEEP survey results from the u* band show that the clustering of the bulk of the star formation does not evolve significantly from z~0 to z~3. Figure 6 also demonstrates the remarkably low noise in the CFHTLS autocorrelation results, providing a significant step with respect to those obtained by Adelberger et al. (2004) near z~1.4

The present study is being complemented by a similar work at larger redshifts, using the other CFHTLS bands. The remarkably high statistics and quality of the photometry will allow to check the redshift evolution of the segregation of the clustering properties with rest-UV luminosity, a key information to constrain models of galaxy formation and evolution.

3.3.3. Joint weak lensing and multi-color analysis of the Deep fields

R. Gavazzi (OMP, Toulouse)

The already available multi-band data set of the deep survey of the T001 release is a key-feature for weak lensing investigations. It is worth mentioning that such a panel of filters will not be achieved in the Wide survey before many months. The principal advantage of multi-band photometry for lensing is that a detailed identification of lensing (deflectors) and lensed (sources) populations is feasible through photometric redshifts. Usually, it is not necessary to precisely estimate the redshift of sources since we only need their statistical distribution. For this purpose the deep survey can act as a calibrator for the sources distribution in the wide survey. For instance, cosmic shear studies do not require detailed photometric redshifts in the whole wide survey. Nevertheless, another kind of weak lensing studies, which is not focused on the matter power spectrum, does depend on the redshift distribution of lenses. More precisely, the correlation between weak lensing-inferred dark matter and optically detected lensing galaxies can only be achieved through a detailed knowledge of the redshift distribution of lenses (although individual redshifts are better). In this respect, the Deep survey turns out to have the best photometric properties though its field of view is reduced.

We have started such a correlation analysis in the deep fields using the T0001 release. At this stage, photometric redshifts are not yet included in the analysis and we will show how critical is the redshift knowledge for further comparison. The first step is the reconstruction of projected mass using the systematic polarization of background sources. These latter are just selected by requiring $22.5<i'<25$ (clearly not optimal!). Figure 7 shows the reconstructed projected density contrast (kappa-map, with kappa being the so-called convergence) in D4. The zoomed highest peak turns out to correspond to a RASS bright cluster located at z=0.13. Except this 6σ significant peak, a few other ones are observed, at level ≤ 3. A direct outcome of mass reconstructions that will be more relevant for the Wide survey is the identification and statistic of such peaks compared to the X-rays and optical methods for clusters of galaxies detections.

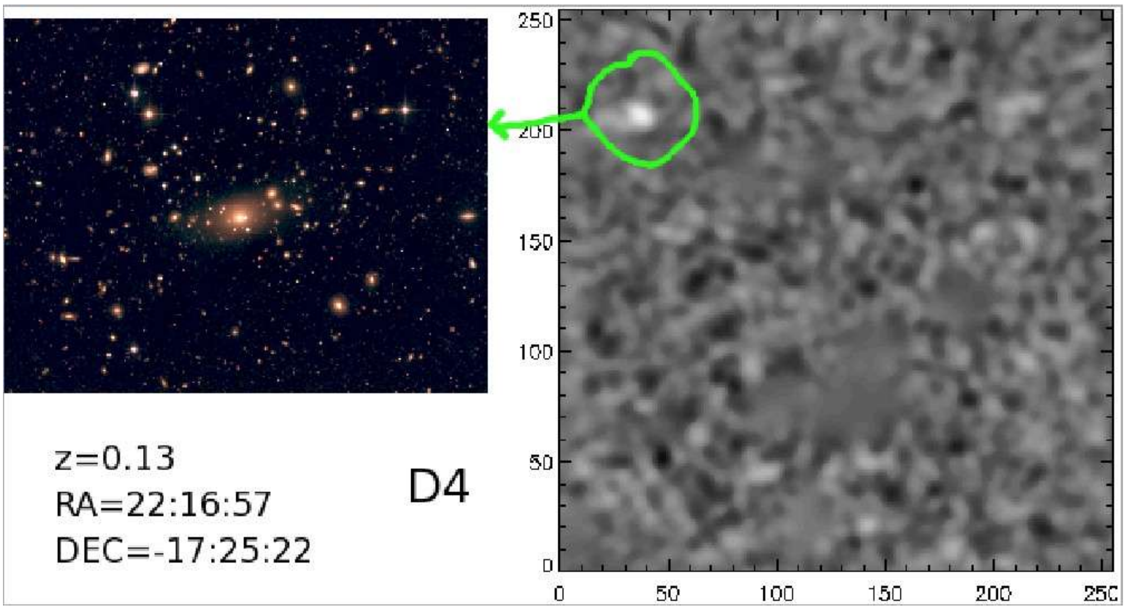

Figure 7: Preliminary weak lensing mass reconstruction of D4. The highest significant peak corresponds to a bright X-ray cluster at z=0.13

Another step consists in the extraction of lensing galaxies. As a test case, we used the following color cuts, optimized for early-type galaxies down to z~0.6: $17<i'<22$, $0<i'-z'<1$, $0.6<r'-i'<2$, $0.5<g'-r'<2.5$ and $0.6<u^*-g'<3$. We then mapped the number density of these objects and compared the inferred density contrast to the kappa-map through a correlation analysis. For the field D1, Figure 8 shows the cross-correlation between kappa and the number density of foreground early-type galaxies (left panel) and between the number density of lenses and the imaginary part of kappa (right panel). The first one presents a central 4σ significant peak while the second one is consistent with noise as expected since gravitation do not produce any rotational component.

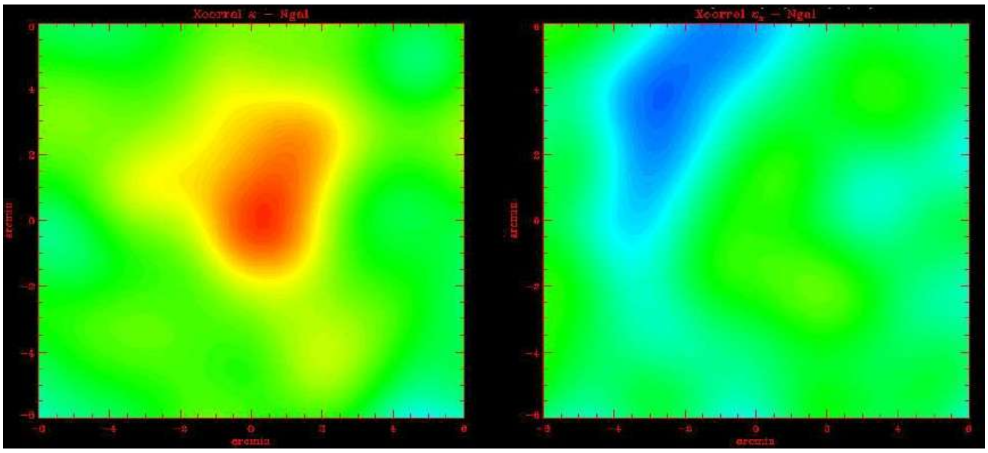

Figure 8: Correlation map between kappa (mass surface over-density) and galaxy number density in D1 on the left. On the right is the correlation between the imaginary part of kappa and the number density, expected to be zero.

From the autocorrelation of light and mass and the cross-correlation between them, it will be possible to infer the relative normalization which is a direct estimate of the bias (or the M/L ratio). This work has been initiated in smaller fields (Gavazzi et al. 2004, Kaiser et al. 1998, Wilson et al. 2001, Gray et al. 2002...) and the general tendency is that early-types faithfully trace the mass with a B band mass-to-light ratio ~300. With good photometric redshifts it will be possible to localize lenses and to separate the contribution of early and late type galaxies. Since the lensing efficiency depends on the ratio between angular distances from lenses to sources, a precise estimate of the lens redshift will enhance the correlation significance which is actually kept at a low level due to raw catalogs selection criteria.

At end, this work could be seen as a peculiar application of galaxy-galaxy lensing. It is worth noticing that the rich photometry of the deep survey could provide interesting applications of galaxy-galaxy (or clusters) lensing at redshifts $z>0.5$, a domain which is a still widely unexplored.

3.4. The Deep stacks as test benches for the Wide survey

With the release T0001 of the 4 Deep fields in 5 bands (except for z' in D4) several preliminary analysis have been started in order to test the validity of the specific tools (like photometric redshifts tools, algorithms to detect clusters of galaxies or weak lensing reconstruction codes for detecting over-densities of masses). Although some of these preliminary scientific exploitations are presented in the Wide report, they are also summarized in this report, because preliminary but exciting scientific results are already emerging from these analysis. The advantages of getting the 5 filters must be put forward, because the present schedule of the Wide survey will most probably favor the angular coverage more than the filter coverage within the next semesters. Consequently most studies which require multi-color photometry in the 5 bands (like the use of photometric redshifts) will be delayed in the Wide and will be favored in the Deep.

3.4.1. Stellar populations in the CFHTLS-Deep

The stellar population analysis in absence of proper motions (not yet possible with the T0001 release) is essentially the same for each of the survey part. The complete analysis is shown in the Wide section. Here we present a summary.

To insure that the objectives of the CFHTLS concerning stars will be reached, we have performed a detailed analysis of the stellar objects detected in the catalogues published in the first release. Photometric and astrometric accuracies, and the star-galaxy separation have been evaluated. While the external astrometric accuracy is estimated to be better than USNO-B the reference catalogue (0.4 arcsec), the internal astrometry is 0.05 arcsec. But due to the small dithering pattern used, oscillations are present which prevent to do very accurate astrometry at the border of the CCDs. Large dithering pattern are supposed to solve this problem. Moreover next release (T0002) is expected to be fully astrometrically calibrated with the new Terapix software Scamp, allowing to exploit the whole field for proper motions.

A detailed photometric analysis has been performed on stellar populations. The morphological star-galaxy classification shows to perform adequately up to i'<21. However, as expected even at these bright magnitudes, compact galaxies and quasars contaminate the star sample. It appears to be sensitive to the seeing, one field (D2) shows the separation to be less efficient than the others. Follow-up in the near-infrared would be much useful to distinguish on the red side stars from galaxies and quasars. Proper motions will also improve the detection for nearby and high velocity stars. Stellar populations well identified in the T0001 release are : spheroid subdwarfs dominating the colour-colour diagrams at r'-i'<0.4, thick disc dwarfs at 0.4<r'-i'<1.2 and thin disc dwarfs at r'-i'>1.2. The stellar densities appear to be as expected from current Galaxy model. The colour-colour diagrams are very useful to distinguish various populations, all filters being well adapted for given stellar types: white dwarfs are best distinguished in u*'-g' vs g'-r' diagram, and brown dwarfs from r'-i vs i'-z'. We have determined the locus of white dwarf -red dwarfs pairs. This locus superimposes the compact galaxy locus but proper motions will be used to extract these objects from the sample. It is already possible to identify some interesting candidates such as probable brown dwarfs (1 in D2, 1 in D3) and a few white dwarfs, although they need confirmation, from near-infrared photometry, spectroscopy and/or proper motions.

3.4.2. First detection of mass over-densities in the Deep fields by weak lensing

As shown in the previous section, the T0001 release of the Deep stacks has been used to explore the different aspects of the use of weak lensing to detect massive structures like the clusters of galaxies. Preliminary results were obtained with crude photometric and color cuts, and a better use of the multi-color information will be added soon. However, in the case of the Wide survey, this multi-color information will be both delayed and shallower, so these preliminary tests should be extended to the present data with the next release T0002. In addition, the comparison between the mass selected structures (through weak lensing) and the optically selected structures will be a direct test of the distribution of the cosmological bias at these scales, or more probably a way to explore the biases introduced by the methods in use for detecting these structures.

3.4.3. Detecting clusters of galaxies in the CFHTLS-Deep

Since the release T0001, the aspects that were addressed were mainly related to understanding of the data, the setting of various parameters for the detection algorithms, as well as the construction of several simulated data sets to mock the "Deep" and "Wide" galaxy catalogs in such a way that at least several cluster properties are represented.

The optical detection algorithms that were selected are two-folded: first the so called *matched filter* where one searches for over-densities assuming a luminosity function and a radial profile, and then an approach based on the assumed color properties of the cluster galaxies, mainly the red-sequence produced by the elliptical galaxies in clusters cores. The first method requires only one pass band, whereas the second at least two, the choice of the bands allowing the access to a particular redshift domain. If the five band-passes are available it is also possible to look for over-densities in the 3-dimensional space given by the position on the sky and the photometric redshift. This approach is currently being addressed using the software "Lephare" developed by S. Arnouts.

Two *matched filter* algorithms are used. The first one, very similar to the one used by Postman et al. (1996), has been originally developed and applied on the 15 sq.deg. of the ESO Imaging Survey.For the time being the matched filter algorithm has been applied on the i' band data of D1 and D3. The resulting cluster counts are compared to the ones obtained with the EIS cluster catalog and provide a good match between the two sets of data. The second one, being currently tested, has been developed by C. Marmo in order to be able to deal with locally varying galaxy counts, reflecting depth variations, particularly important for the mosaics of the Wide fields. To obtain a good understanding of the differences between the two matched filter implementations a number of simulated cluster catalogs have also been produced, which analysis is still in progress.

The other approach that has been initiated on D1 is the detection of over-densities in both position on the sky and colour. Assuming that the systems of interest are composed by a large fraction of early type galaxies presenting a tight sequence in a well chosen colour-magnitude diagram (red-sequence), projected over-densities in a given colour slice may indicate the presence of a cluster whose redshift can be estimated photometrically. At low redshift the brightest peaks match well with the Matched filter detections, whereas at larger redshifts comparisons between the methods and with simulations are still going on.

3.5. Conclusion

It is clear from the above sections that most of the scientific exploitation of the CFHTLS-Deep is just starting and that the present stacks are not deep enough to be really competitive with other deep surveys (HDF-N or S, COMBO17, the CFH12K/VIRMOS deep survey, etc ...). The first release of the Deep stacks has been available since less than 4 months ago, and most of the scientists have already demonstrated that their tools are in place and that the scientific validation of the data has started. They are urgently waiting for the deeper stacks foreseen for T0002 in order to start more competitive scientific projects. In fact, the CFHTLS-Deep will become more and more competitive as observations are progressing, so scientific publications should wait for deeper data than the presently available ones.

On the operational point of view, the major difficulty in the Deep survey is to try to get a correct filter balance over the semesters. In particular u* observations should be given more priority at least for 2 semesters in order to compensate for the present low success of this part of the survey. This is the major requirement expressed by the CFHTLS-Deep users, although the importance of image quality in the observations also remains a concern.

Finally, as WIRCAM is foreseen to be on the telescope within the next months, a near-IR follow-up of the Deep fields is emerging in the community and should appear as a natural continuation of the CFHTLS-Deep survey, at least in one or two of the 4 fields.