MegaCam Survey Working Group

The CFHLS

The Canada France Hawaii Legacy Survey

Report to the CFHT Science Advisory Council

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The MSWG

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1 Preamble

This document presents a proposal for a Legacy Survey, the CFHLS, to be performed with the CFHT MegaPrime, over five years, at a rate of 105 nights per year for a total of 525 scheduled nights in queued and service observing (QSO) mode. In defining the CFHLS, the MegaCam Survey Working Group (herein referred to as the WG), took the following points into account:

1. MegaPrime, a brand new prime focus and the MegaCam camera, should be operational for the Fall of 2002. MegaPrime will provide CFHT for at least 4 years with a unique instrument capable of unprecedented field size and image quality. The WG notes that this advantage will be lost when a visible camera becomes operational on the VISTA telescope (around 2006/2007).

2. By the end of 2002, only one other instrument (MOS/OSIS) should compete with MegaPrime for dark time. Though the time allocation committees will have the final decision, we anticipate that MegaPrime will be on the telescope for the majority of the dark time. The commitment of large blocks of time to MegaPrime provides the opportunity to allocate a significant number of nights to large programs, surveys, while still leaving a sizeable number of nights open to traditional proposals.

3. The WG believes that the uniqueness of MegaPrime and the investments made in France and Canada justify the allocation of a significant fraction of its scheduled observations to one major survey, the CFHLS. The main drivers of the CFHLS have been chosen for their scientific value, taking into account the capabilities that make MegaPrime unique. CFHLS starting before the end of 2002 has no competition, if done at the level requested.

4. Insuring the CFHLS data yield, quality control and processing is an exciting challenge facing us, requiring a level of integration and interaction of CFHT, CADC, and TERAPIX that has not existed up to this point. By offering our scientific communities unlimited and equal access to the CFHLS images, we are proposing a way of managing both telescope time and data handling which is without any precedent on such a scale. Beside the well-identified projects for which the CFHLS has been designed, any one of the hundreds of scientists in our communities will have the opportunity to do with the CFHLS data whatever they want, without worrying about data ownership, PI exclusivity or Time Allocation Committee filtering. The commitment of existing groups for the main scientific drivers of the CFHLS and the huge number of potential users for nearly any application of wide field imaging one can think of are the best guarantee of a huge scientific impact in the coming years, the *raison d'être* of the CFHLS.

This report presents a design of what could be the CFHLS based on many discussions held within the Canadian and French communities, on recommendations made by the CFHT Science Advisory Council (SAC), and on discussions and exchanges at and between the various institutes which are going to play a key role in the CFHLS.

2 The CFHLS in short

The magnitudes given in this section are for $5\sigma/1.16$" ap. point source detections and are expressed in the Vega system.

2.1 Three surveys... from the solar system to the remote universe

2.1.1 A very wide shallow survey

Covering 5000 square degrees in two filters on the ecliptic, the survey will be made of sequences of three 2mn r' exposures (r'=24.1 on a single exposure, 24.7 if stacked) and one 2mn exposure in z', reaching z' = 22.0. About half of the fields will be selected so that they coincide with regions of star formation and the Pleiades and Hyades young open clusters. The observations will be sequenced on a night in r' over at least three hours with the z' observation the following day. This survey will provide an unprecedented sampling of our galaxy and a unique exploration of the ecliptic, leading to more than 2000 Kuiper Belt Object discoveries, including a few Neptune-like objects (if any), and to a first sampling to such a depth on such a field of the Main Belt and Near Earth asteroids. In the star-forming regions and young Pleiades and Hyades clusters, hundreds of brown dwarfs with ages between 1 Myr and 600 Myr and dozens of edge-on disks will be discovered. This survey will provide the most numerous sample of objects for studies of brown dwarf formation and evolution, and of the evolution and structure of circumstellar disks around pre-main sequence stars.

2.1.2 A wide synoptic survey

Covering 208 square degrees in four patches, three of 6×6 square degrees and one of 10×10, through the whole filter set (u*g'r'i'z') down to i'=24.5, this survey will allow the study of the large scale structures and matter distribution in the universe, through weak lensing and galaxy distribution. Thanks to the sequencing of the r' observations in two phases, early in the survey and three years later, proper motions will be available for galactic structure studies. All fields will be used for stellar population investigations and searched for moving objects and transient phenomena.

2.1.3 A deep synoptic survey

Covering 4 square degrees in four MegaCam fields through the whole filter set (u*g'r'i'z') with integration times ranging from 33 to 132 hours depending on the filter (u*:33 g':33, r':66, i':132, z':66), this survey will be sequenced over 5 years at an average rate of 5.25 nights a dark run for 5 runs in a row each year on each field. Aimed mainly at the detection and monitoring of as many as 2000 type I SNe and at the study of the galaxy distribution on images reaching r'$\simeq$ 28, this survey will allow a better understanding of the early universe as well as a determination of the dark energy parameter w with an unprecedented accuracy. The 10^6 galaxies and 10^4 quasars will allow to build statistical samples bringing strong constraints on galaxy evolution and global star formation history. Thanks to the sequencing, transient phenomena and moving objects will be detected and followed up, providing a unique monitoring over five years of fields at various galactic and ecliptic latitudes.

2.2 The CFHLS at a glance

Survey *Location* *(tentative)*	area deg x deg	filters	depth $5\sigma/1.15$" point source	total exp time	observing strategy	Total nights
Very Wide						
Ecliptic	5000	r'	24.1 (2mn)	3x2mn	spread over 2 hrs	
+/- 7 deg		z'	22.0	2mn	2 day after r' obs.	**127**
Wide Synoptic						
02:20 -5 (XMM)	10x10	u*	25.5	6000 s		
10:00 0	6x6	g'	26.5	2500 s		
14:00 +52	6x6	r'	25.7	2000 s	1000 s early	
(Groth Strip)					1000 s 3yrs later	
22:00 0	6x6	i'	25.5	4300 s		
		z'	24.0	7200 s		**196**
Deep Synoptic						
A 1x1 subset	4(1x1)	u*	27	33 hr	5.25 nights	
of each of the		g'	28.4	33 hr	per run	
fields of the		r'	28	66 hr	5 runs a year	
Wide Synoptic		i'	27.8	132 hr	for each field	
		z'	26	66 hr		**202**

- Fields for the Wide Synoptic survey have been selected for their interest (XMM LSS field and Groth Strip) and the fact that they allow a spread of the observations all along the year. Other choices can be made, though the 10x10 patch makes really sense on the XMM field.
- The expected performances reached by MegaPrime, expressed in the Vega system, have been computed by various groups using the CFH12K performances measured on the sky and the characteristics of the various components of MegaPrime, from the wide field corrector to the CCDs of MegaCam. They are summarized in the following table:

	u*	g'	r'	i'	z'
limiting magnitudes (Vega)					
30mn - 0.8" seeing - $5\sigma/1.16$" ap. - point source	24.9	26.4	25.5	24.9	23.4
30mn - 0.8" seeing - $5\sigma/3$" ap. - extended source	23.9	25.4	24.5	23.9	22.4

- The CFHLS would mainly need a seeing of 0.9" or better, which is anticipated to happen 85% of the clear observing time.

2.3 How many nights?

The CFHLS will require 525 scheduled nights in Queued Service Observing (QSO) mode, based on the current definition of a QSO night (6.5 hr of integration on science fields). The QSO night takes into account the overheads for calibrations and the fraction of the time lost to bad weather. If the CFHLS is implemented with the participation of all the CFH communities, about 41% of the available dark/gray time with a seeing of 0.9" or better will still be open to original programs at the discretion of the Time Allocation Committees. This percentage will still be larger than 30% if UH does not participate.

3 Science

3.1 The Open Kuiper Belt Project

More than 50 planets around other stars have been discovered in the past few years. As a result of detection biases all these planetary systems are dominated by the presence of a large gas giant (Jovian) planet or planets. An extremely interesting benefit of these discoveries is that they have motivated closer investigations of the formation of our solar system's gas giant planets (Jupiter, Saturn, Uranus and Neptune). The formation of the planetary system of our Sun was a complex process and the details of this process are not well defined. Questions as basic as the location of the formation of the planets and their mode of formation (single phase collapse or agglomeration) remain unanswered. In addition, understanding the formation of the giant planets by studying their current properties is complicated by the fact that they are now physically and chemically evolved.

Extensive surveys of the asteroid belt have been used to map the dynamical structure of this region and the details of the inner solar system's orbital dynamics. The measured dynamics have, in turn, stimulated detailed numerical modeling of the inner solar system and allowed the dynamical history of the region to be examined. Links to asteroid families via meteoritic studies have led to the determination of the composition of the proto-planetary nebula. Studies of the asteroid belt have also been crucial to understanding the histories of the terrestrial planets. For example, the study of meteorites (strongly linked to the main asteroid belt) has yielded abundant information on the physical conditions in the proto-solar nebulae in the 2-4 AU range (1 AU is 150 million km). The asteroidal orbit distribution has been sculpted by gravitational interactions with the planets over the lifetime of the solar system (Murray and Holman 1997) and, during the more violent period of the solar system's formation, by larger bodies passing through it (Petit et al. 1999).

For the outer solar system, however, the lack of small body belts with semi-major axes exterior to Jupiter meant that similar studies were not possible for the giant planets. Kuiper (1951) suggested the existence of a belt of material in orbits with semi-major axis between 30 and 50AU, based on the observed distribution of short period comet orbits. Gladman and Duncan (1990) and Holman and Wisdom (1993) showed that after the giant planets reached their current masses the regions between them would be emptied of planetesimals on time scales much smaller than the age of the solar system. However, these studies also showed that outside of Neptune the hypothesized "Kuiper Belt" was stable, supporting modeling of Duncan et al. (1987) that the short-period comets come from this source via long-term gravitational instability. The general picture developed from these studies was that a dynamically cold Kuiper belt outside Neptune represented a leftover fossil of the planetesimal disk, in which large planets had not formed.

Following the discovery of the first Trans Neptunian Object (TNO) by Jewitt & Luu (1993), more than 400 TNOs have been discovered, confirming that there is indeed a "Kuiper Belt" (see Figure 1 for a location of most of the known TNOs).

At a geocentric distance Δ with physical radius r and geometric albedo p, TNOs have apparent magnitudes given by the scaling ratio:

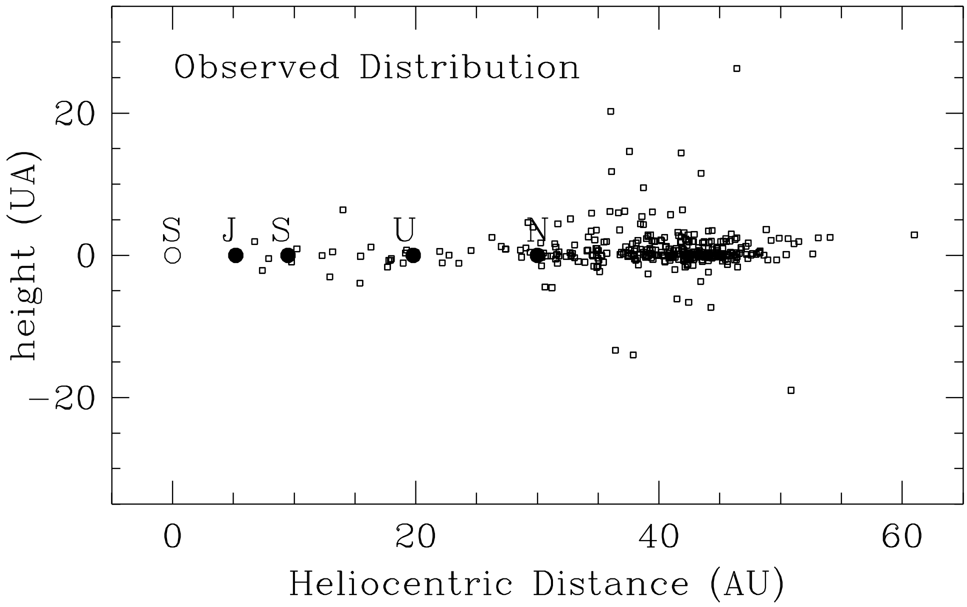

Figure 1: The outer solar system. The boxes are at the current locations of known outer solar system objects. The term "Kuiper Belt" is used to denote the material beyond Neptune.

$$m_R = 23.5 + 2.5 \log_{10} \left[\left(\frac{p}{0.04} \right)^{-1} \left(\frac{r}{50\ \text{km}} \right)^{-2} \left(\frac{\Delta}{35\ \text{AU}} \right)^{4} \right], \tag{1}$$

When observed at opposition TNOs move with a retrograde motion of roughly $\frac{150}{\Delta}$ arcsec/hour, due to the reflex motion induced by the Earth. This motion, at typical rates of 3-5 arcsec/hour, is used to find the objects against the stellar background. The Δ^{-4} law of apparent brightness affects all objects seen by reflected light and implies that the more distant TNOs become very difficult to spot. However, they are within reach of 4-meter class telescopes, such as the CFHT, out to $\Delta \sim 200$ AU.

The goal of this project is to provide a comprehensive survey of the contents of the outer solar system. To make the survey feasible we will limit our sensitivity to the larger members of the ecliptic plane, discovering those outer solar system bodies which are most easily accessible for tracking and physical studies. Mapping the structure of the Kuiper Belt will constrain models of the formation of the giant planets. Measurements of the physical properties of TNOs will provide a direct measurement of the chemical properties of the Sun's proto-planetary nebula. Understanding the Kuiper Belt is a crucial step to understanding the formation of gas giant planets.

3.1.1 Questions in Planet Formation

The Kuiper Belt is not the cold quiet place which many expected. Instead, we have found a dynamically excited, heavily depleted belt of material. Numerous questions have sprung from this discovery:

- What caused the dynamical excitation in the belt? Current suggestions include: a close stellar passage, the scatter of lunar sized bodies from the inner solar system into this region and the scatter of a nascent Neptune into the region. Each of these scenarios, and others, provides a unique signature in the orbital dynamics of the region. Only an extensive catalog of orbital information will reveal the truth.

- Can objects form in the region beyond 50AU? Currently there are no objects on circular orbits beyond 50AU from the Sun. Why? Again a number of explanations have been proposed. Perhaps a close stellar encounter would truncate the disk at some radius. Perhaps the Sun was born in a nursery of stars and photo-evaporation remove much of the material. Additionally, recent modeling suggests that the actual process of dust accretion and growth may not function on rapid enough time scale in this region. A survey covering a wide area of the ecliptic will allow the detection of the apparently rare objects in this region of the solar system.

- What is the size distribution of material? Crucial to understanding the processes of dust accretion and planetesimal growth is a measure of the actual *size distribution* of large planetesimals (100-500km) in the Belt. Are these objects distributed in a "cascade" of sizes, caused by the competing effects of accretion and erosion or, is the distribution of sizes indicative of only one of these processes. The Belt is now known to contain multiple components and there is growing evidence that these components possess unique size distributions.

- What is the largest member of the belt? Tombaugh's discovery of Pluto was aided by Pluto's close approach. However, there is now reason to expect that Pluto is not the most massive member of this region. A comprehensive and complete survey has a chance to determine the largest member of the population and thus further guide our understanding of planetesimal accretion.

In addition to these questions new ones will undoubtedly arise. Currently astronomers only know the structure of this region of the solar system to the 0^{th} order: the Kuiper Belt contains material. Our lack of knowledge of the full content of this region severely constrains the understanding of our solar system. Only a large scale survey of the region can solve these riddles.

3.1.2 The Survey

The process of surveying the Kuiper Belt can be considered in three basic steps; discovery, tracking and physical study.

- Discovery The issues surrounding the discovery of new TNOs are intimately tied to the processes of tracking and physical study. To avoid placing too large a burden on recovery facilities tracking newly discovered objects, it is better to keep the rate of discoveries constant and the faintness of targets above some reasonable magnitude threshold. Our experience is that objects much fainter than r'=24 are too faint to be tracked economically and are not useful for physical study.

To first-order the luminosity function of TNOs can be described by a single power-law,

$$\Sigma(m_R < R) = 10^{\alpha*(R-R_0)}$$

where $R_0 = 23.5 \pm 0.2$ and $\alpha = 0.68 \pm 0.3$. This function provides the distribution of material on the ecliptic. The actual width of the observed latitude distribution of material remains controversial but a reasonable description is a Gaussian of width $\sigma = 10^o$. Given this distribution we expect about 1.5 detected objects brighter than $m_R = 24.0$ per square degree for fields near the ecliptic, dropping to about 0.75 detected per square degree at 10 degrees above or below the plane.

Conditions for an efficient survey suggest that the camera should cover approximately one square degree to allow one useful detection per camera pointing. The CFHT with MegaCam is the only instrument in the world that will allow this survey to be conducted efficiently.

Discovery will involve **a set of three exposures per field each separated by about one hour in time**. The exposure time will be set to detect point source of R=23.8 with S/N = 8.0 (required for moving object detection). The current description of the MegaCam+CFHT QE indicates that this depth will be attained using **2 minute exposures** in seeing of 0.8". Thus, each field will require a total of 6 minutes.

- Tracking Once objects have been discovered they must be followed to allow correct orbit determination. Days after detection, at least one image has to be made to confirm the detection and improve the very crude orbital elements determined during discovery. An object is not really considered as discovered without this second night acquisition. A few months after detection a second set of exposures is used to detect the object and further improve the orbital determination. Without this second "check-up" observation about 20% of all discovered objects will be lost. A year after discovery, observations of the object on at least two nights have to be made to recover the known objects. Finally, 2 years after discovery a final recovery observation is made. After the 3 discovery exposures each TNO is observed 5 additional times using between 7 and 15 additional exposures depending on the strategy chosen. The tracking to discovery load ratio is then of the order of 4:1.

  The very wide shallow survey design will offer a z' image in the night following the discovery exposures or a few nights later depending on the weather. Though this second visit will be two magnitudes brighter than the r' discovery images, about 40% of the discovered objects (the bright ones and the reddest ones) will get their second night observation directly from the survey.

  The tracking observations are made using appropriately apertured facilities and does not usually require use of a wide field imager. As discoveries will be made immediately available to the world, it is anticipated that the tracking will indeed be insured through a global effort. The well-established collaboration within the French-Canadian group already pursuing a large program on the Kuiper Belt with CFH12K would play a key role: collaborators at the Nordic Optical Telescope could track brighter objects (16 nights per year allocated under thesis/long term status), TNO of intermediate brightness could be tracked using the Mt. Palomar 5m (8 nights per year allocated for the past 5 years) and fainter candidates could be tracked using the MMT, Magellan (via collaborators at SAO, 4 nights per year on each) and VLT (4 nights allocated in 2001) facilities. As other collaborations are likely to arise thanks to the interest of this very wide survey, tracking observation needs should be well covered.

Even with this rigorous follow-up program some objects will need to be observed more frequently as their orbits may lie near resonance regions and so precise elements will be essential. On rare occasions (1 in 100) objects will lie on orbits which take them far from the first guess ephemeris and these will need to be recovered using a wide field imager. Some of these recoveries could be done with MegaPrime on a very light PI-mode program (a few objects a semester).

- Physical Studies The brighter objects discovered in the survey will be the targets of intense spectro-photometric follow-up. The physical characteristics of the belt material are very poorly developed and the large pool of objects bright enough for follow-up will be one of the great legacies of this project. Collaborators of the French-Canadian group already undertake such efforts using ESO. As with the tracking needs, these collaborations are likely to be extended to other groups and facilities.

3.1.3 Survey Requirements... Why 5000 square degrees?

There are two distinct requirements of the survey. A large number of objects must be found to allow the relative strengths of various orbital resonance of the belt to be determined. The relative populations of the resonances can be used to diagnose the past migration of Neptune and to test theories about the Neptune's formation and possible stellar encounters. The second goal of the survey is the detection of spatially rare objects. The largest members of the belt, which are useful for physical study, have a surface density of a few per 100 square degrees. In addition to this group the final question of the survey will be to determine the maximum size of objects in the belt. The current observed dynamics of the belt material could be caused by lunar sized bodies lodge in the belt. Only a few (3-10) such objects would be needed and their discovery would have profound effects on models of the solar system's formation. Discovery of such bodies will be difficult as they could be anywhere inside the approximately 10000 square degrees of the ecliptic plane.

- It does not sound realistic to ask for these 10000 square degrees, though it would allow a more thorough exploration of the ecliptic. It would be too large a fraction of what can be reasonably allocated to the CFHLS.

- To stay to 1000 square degrees is not going to be a major step with respect to ongoing or planned *small* surveys.

The proposed 5000 square degrees, or ± 7 degrees from the ecliptic plane, are a good compromise, covering a significant part of the ecliptic, bringing a real breakthrough in our knowledge of the Kuiper Belt, while being limited to less than one fourth of the CFHLS.

The Hyades, Pleiades and the Taurus-Auriga stellar forming regions will be covered and the total area is large enough to offer a nice sample of our Galaxy (see 3.2).

3.1.4 Number of Nights

Based on integration times of 6 minutes per discovery field and the desire to cover a broad region of the outer solar system (5000 sq. degrees at a minimum) this survey will require 6x5000 minutes of integration or 77 queue nights. Given the short exposure time and frequent pointing change some counting of overhead costs must also be done. Test observations made using the CFH12K in binned mode (approximately the same readout speed as the MegaCam) indicated that a dwell time of only 30 seconds can be attained. Accounting for this overhead expands the required time to 7.5 minutes per fields or 96 queue nights, accounting for three quarters of the very wide shallow survey. The z' exposures, the last quarter of this very wide survey, will provide an opportunity to follow around 40 % of the discovered TNOs. While this additional exposure is scheduled to provide this follow-up opportunity, its filter is chosen for providing color information to the galactic side of the very wide component of the CFHLS.

3.2 Our Galaxy

3.2.1 Search for white dwarfs in the galactic halo

Micro-lensing experiments have suggested that at least a part of the dark matter halo of our Galaxy may be constituted of stellar remnants. The probable mass of sources of micro-lensing events is about 0.5 solar masses, compatible with the mass of white dwarfs. These objects could make between 10 and 50% of the dark matter halo. The colors of these very cool objects are suspected to be between 0 and 1.2 in V-I while their absolute magnitude can range between 14 and 19. This allows detecting them at distances closer than few hundred parsecs. They have colors similar to subdwarfs and galaxies. So the only way to detect them among numerous blue objects is to measure their motion.

At magnitude V=24 (25 respectively), simulations show that, if the fraction of dark matter is 100% in these objects, one could select by their proper motions about 30 (65 respectively) such objects per 10 square degree field, with a significant proper motion measured on 4 years.

In the wide synoptic survey, even if the fraction of halo dark matter is only 10% in white dwarfs (WD), and the halo is 12 Gyr old, we could detect more than 100 of these objects. With only 2 epochs one cannot get rid of the galaxies which can have false motions because of uncertain centroiding on extended objects and/or variabilities on a part of their surface. 3 epochs would insure the detection of real moving stellar objects. It is anticipated to have two visits at least three years apart for each of the fields of this wide synoptic component of the CFHLS. A third visit will be a natural follow-up to the CFHLS itself.

In the deep synoptic survey, it will be useful to stack a large number of images, but not all in order to detect proper motions and, for some of the candidates, parallaxes. They will be very efficient to evaluate their absolute magnitude and test the still uncertain theory of very cool white dwarfs.

Many white dwarfs will be detected in the very wide survey. However they will be mainly disc WD and proper motions will lack to distinguish the ancient white dwarfs from distant subdwarfs. A good estimation of the disc WD luminosity function will be obtained, allowing a measure of the galactic disc age. A modest extension (100-150 deg^2) of this very wide survey could be made toward the Galactic Disk, in particular to complement the SIRTF Legacy Survey, GLIMPSE.

3.2.2 Brown dwarfs

The proposed survey characteristics are of considerable interest to measure the luminosity function and spatial distribution of brown dwarfs. Numerous brown dwarfs (BD) have now been found, in young clusters, and in the field from near-infrared (DENIS, 2MASS) and optical (SDSS) surveys. Their spectral characteristics divide them in two classes: L dwarfs have effective temperature between 1500K and 2200K, and their spectra differ from M dwarfs by the absence of the TiO and VO optical bands. T dwarfs are cooler ($T_{\rm eff} \sim$ 1200K and lower), and are characterized by methane bands in their near-IR spectra.

The ongoing sky surveys will discover a few hundred L dwarfs and a few dozen T dwarfs (among the hottest). They will however probably not detect any BD cooler than about

800K, and will only provide very limited information on the luminosity function and scale height of warmer BDs.

The proposed CFHLS will observe L dwarfs at distances up to 90pc in the very wide survey, 230 pc in the wide synoptic survey, and 1300 pc in the deep survey. This provides large sampling volumes at both small and large distances, allowing to constrain the scale height as well as the luminosity function for each population. The CFHLS will improve our knowledge of BD physics on four important points :

- Detection and physics of very cool T dwarfs ($T_{\rm eff} < 1000$ K). Objects as light as 10 Jupiter mass have been identified in young clusters (Zapatero Osorio et al. 1999, Lucas & Roche 2000), but are so young there that they have only cooled to approximately 2000K, an L-dwarf temperature. They have no internal energy source, and will thus rapidly cool down much further. By an age of a few gigayears such objects reach effective temperatures of 200 to 400K (Burrows et al. 1997), and are much too faint to be found in existing surveys. The CFHLS will detect some of them, in particular if it is complemented by a WIRCAM survey. Follow-up with 8m telescopes will give tremendous constraints on the physics of BD and giant planets.

- Statistics of brown dwarfs of intermediate temperature (1000 to 1500 K). At these temperatures the luminosity function obtained with DENIS, 2MASS and SDSS surveys will be restricted. The CFHLS will detect several hundred down to 20 Jupiter masses, accurately determining the luminosity function. The CFHLS will also detect numerous objects intermediate between the L and T classes (see Table 1). The duration of the transition depends on the speed of atmospheric dust settling in the atmosphere, which is presently unknown. The observation of numerous objects in the transition phase will illuminate the physics of this crucial phase.

- Brown dwarfs in the thick disc and spheroid. Thick disc and spheroid populations are scarce in the solar neighborhood, and thin disc contamination only becomes manageable at about twice the scale height of that dominant population. This is out of reach of current surveys. Their density will give constraints on the fraction of the dark halo made of brown dwarfs. Another product will be the low mass end of the IMF (initial mass function) for these two populations of different metallicities, giving a strong test of the universality of the IMF.

  Halo brown dwarf proper motions will be measurable during the 5-year survey. At 1 kpc, one expects their proper motion to be of the order of 50 mas/yr (for a velocity lag of 220 km/s), and about 10 mas/yr for thick disc BD. The latter will be more numerous and reachable at closer distances.

- L dwarf scale height and age. In these objects there is no one to one relation between mass and temperature: young very low mass objects and older, but more massive, ones can have the same temperature. The mean scale height at a given temperature constrains the age distribution: (very) young populations have a scale height close to that of the extreme population I (about 60 pc), while older objects have higher scale heights, up to 200 pc for the old disc.

Table 1 gives the expected number of detected brown dwarfs at different temperatures. These numbers have been computed by Delfosse and Forveille (private communication) under the following assumptions: the densities of disc L dwarfs are measured from the analysis of 5000 square degree of DENIS data; T dwarfs are assumed to have the same local density (a priori a conservative estimate); the absolute magnitudes are 20 in r' and 18 in i' for an early L dwarf, 22 in i' and 18 in z' for a T dwarf of temperature 1000K, 28.5 in i' and 23.5 in z' for a T dwarf of 300K. These numbers are measured from objects having measured parallaxes down to 1000K and come from models by Burrows et al. and Baraffe et al.

Type of objects	distance limits wide CFHLS	deep CFHLS	deep + WIRCAM	Nb of objects wide CFHLS	deep CFHLS	deep + WIRCAM
L Dwarfs	229 pc	1300 pc	1300pc	6000	few 10000[1]	few 10000[1]
$T_{eff} \sim 1000K$	30pc	200pc	500pc	~10	~100	~1000[1]
$T_{eff} \sim 300K$	2pc	12.5 pc	50 pc	0	0	few objects

Table 1: Maximum distances and expected numbers of brown dwarfs in the CFHLS, and in the CFHLS complemented by WIRCAM, assuming detection at 5 sigmas at J=26 in a WIRCAM deep survey. Numbers with superscript[1] depend on the assumed scale height for the disc and local density of the thick disc and spheroid.

3.2.3 Variabilities

None of the three components of the CFHLS is designed to study variabilities, and any attempt to use the data in that field will have to deal with strategies established for other goals. Does it mean that nothing can be done versus variabilities? Certainly not!

The deep synoptic survey with a time constraint of 2 days will allow to detect all variables of period larger than this, but the covered area is small and the expected numbers too. But little is known about variabilities among late type dwarfs. This will be a good opportunity to study the low mass stars variabilities, as well as variabilities among subdwarfs.

While the 1-hour exposure images in each filter will be done in several exposure of few minutes, it gives the opportunity to detect short time variabilities, like RR Lyraes and compact binaries, through a unique 4 point sampling. The sampling rate is about right to identify 0.5 day periods and separate them out from long period variables. One expects about one RR Lyrae per square degree at high galactic latitudes, at apparent magnitudes between 18 and 22. Due to the well defined period-luminosity relation, RR Lyraes are a good tracer of the halo density law. The very wide survey would allow to detect a quite large sample giving access to the edge of the galactic halo. A key science goal would be to identify the "spaghetti structure" of the halo which is a record of its assembly. This would constitute a huge breakthrough and is only possible for our own galaxy. There is certainly much simulation work needed to assess in a better way what can be done, but this area seems very promising and data will naturally come from the very wide survey anyway.

Compact binaries are expected to be about 1 percent of the observed stars in the galactic plane (Alard, private communication). A large number of them will be detected, as RR Lyraes, by simply comparing short exposures take during one night. This has to be done at the same time as the search for solar system objects, before stacking individual images.

3.2.4 Two spinoffs...

The Low-Luminosity Population of the Taurus-Auriga Star Forming Region One the closest prototypical star forming regions, the Taurus-Auriga molecular clouds, happens to be located close to the ecliptic plane. For example, the multiple system T Tauri, which lends its name to the class of very young low-mass pre-main sequence stars known as T Tauri stars, has an ecliptic latitude of -2 degrees.

Two modes of star formation seem to exist: a distributed mode associated mostly to diffuse, low-mass star forming regions and a clustered one observed in denser and more massive environments. The Taurus-Auriga region samples the diffuse mode, and therefore play a central role in our understanding of the star formation process. While deep pointed studies of very young clusters have been made with very successful results, such as the discovery of brown dwarfs and free-floating planets in the Sigma Orionis cluster (Zapatero Osorio et al. 2000), the deep study of diffuse regions is much more difficult because of their large size. The angular size of the Taurus-Auriga region is more than 100 square degrees. To date less than 5% of the total cloud surface areas have been imaged in the visible down to typical sensitivities of I=19. A significant fraction of the low luminosity stellar population is thus still missing. The Very Wide CFHLS survey can increase by 1 to 2 orders of magnitude the area covered and improve by a factor 3-5 the sensitivity of current surveys, thus providing the most complete optical census to date (and for a long time) of the low luminosity embedded population on the scale of a whole molecular cloud. Many outstanding issues regarding the star formation process could be addressed with the help of these data:

- Probe the low mass end of the IMF down to the brown dwarf regime and investigate whether differences occur in different cloud populations. Young star forming regions represent one of our best opportunities to determine the initial mass function as they probe co-eval star populations which still keep track of their initial conditions.
- Investigate the spatial distribution of the low luminosity sources, especially their clustering properties and relation to the massive stars. Whether the vast majority of stars form in a cluster environment is still an open question, which has important bearing on the evolution of the protostellar environment as well as formation of multiple systems. Studying star formation regions with and without high mass stars is therefore important for comparison purposes.
- Study the star formation history throughout the cloud: what initiates the star formation process? Does star formation take place simultaneously and in bursts over the whole cloud or is it a continuous process?

Large-scale optical imaging surveys appear as a necessary complement to the on-going near-IR surveys like 2mass (JHK) and Denis (IHK) with typical completeness limits of I=18, J=16, H=15 and K=14.5. In the case of young stellar objects, the R, I and z wavelength domains are the least affected by circumstellar excess emission, thus allowing the most accurate determination of photospheric effective temperature and luminosity. A reliable estimate of these two parameters is essential for deriving individual ages and masses. In addition, while the near-infrared surveys will remain more sensitive in the most obscured regions of the cloud ($Av > 5$ typically), an optical survey reaching sensitivities of R=24 would allow probing the very low mass population on the cloud surface more efficiently.

The Taurus dark cloud, with total gas mass of $10^4 M_{sun}$, is among the closest star-forming region to the sun at a distance of 140 pc. It mainly forms low-mass stars, distributed loosely across the cloud surface or gathering in small aggregates of 10-15 members. Our scenario for individual star formation is almost entirely based on the study of individual young stars associated with this cloud. To date, the census of the population is complete down to I=12.5 (Kenyon and Hartmann 1995), corresponding to a stellar mass of $0.3 M_{sun}$ at the age of the Taurus population (4 Myrs). A significant fraction of the very low mass objects is thus still missing. The average low extinction ($Av = 1$) associated with this cloud, as well as its young age, combine to provide a high sensitivity to very low mass objects in the optical. According to current evolutionary track predictions (Baraffe et al. 1998), reaching sensitivities of R=24 would allow to detect stars with masses down to 0.02 M_{sun}, i.e. well into the brown dwarf regime. 2 deg^2 have been recently imaged by Briceno et al. (1998) down to I=19, R=21.5 and revealed 9 new very low-mass T Tauri candidates. Very recently, Martín et al. (2001) have presented the discovery of four Taurus brown dwarfs in a survey of 2.3 square degrees carried out with CFH12K. The brown dwarf candidates were first selected using R and I photometry, complemented with 2MASS data. Menard et al. (2001, in preparation) found one edge-on disk using the same data as for the brown dwarf discoveries. A deep very wide photometric survey of Taurus-Auriga would allow to increase by at least an order of magnitude the numbers of very low-mass objects known in this cloud and to obtain **the first reliable estimate of the IMF well into the brown dwarf regime in a star forming region**. It will also allow the discovery of dozens of edge-on disks. The study of the properties of edge-on disks can provide very valuable information about the process of planet building in young low-mass stars.

Evolution of Brown Dwarfs in the Hyades and Pleiades Much of our knowledge of stellar evolution is based on detailed studies of stars in nearby open clusters. The Pleiades and Hyades cluster are among the nearest open clusters. Their ages are 120 Myr and 600 Myr, respectively. About 20 brown dwarf Pleiades members are known so far (Martí n et al. 2000, Moraux et al. 2001), but less than 5% of the cluster area has been surveyed. No Hyades brown dwarfs have been discovered yet despite several attempts (Reid & Hawley 1999).

The core of the Pleiades cluster is located at ecliptic latitude of 4.1 degrees. On the other hand, the core of the Hyades is at ecliptic latitude of -5.8 degrees. For both clusters, the central regions have already been surveyed for substellar members and do not need to be included in the CFHLS. The very wide survey of CFHLS offers the splendid opportunity of searching for brown dwarf cluster members over a much wider area, extending into the coronae of the clusters. With a sensitivity of r'=24 and z'=22, the CFHLS will detect brown dwarfs down to 0.03 solar masses in the Pleiades, and down to 0.055 solar masses in the Hyades. CFHLS can cover 20 square degrees in the Pleiades and 100 square degrees in the Hyades, leading to the detection of about 200 brown dwarfs. This would be the largest sample of brown dwarfs of known age and distance. It would allow to derive the substellar IMF for both clusters, and to study the evolutionary properties of brown dwarfs, such as the time dependence of binarity, chromospheric activity, and rotation. The brown dwarf candidates would be selected using color-magnitude diagrams. Follow-up observations would include near-infrared photometry with 2-meter class telescopes, spectroscopy with 8-meter class telescopes, and proper motion studies with CFHT a few years after completion of the survey.

3.3 Weak-lensing

3.3.1 Scientific objectives

The analysis of gravitational lensing of background galaxies by foreground structures has the capability of measuring many of the important properties of the mass distribution of the universe with great precision and minimal concerns about the problems of "tracers" such as galaxies or hot gas. The potential of such measurements was recognized about 40 years ago but entered its modern phase about 15 years ago with the discovery of arcs in galaxy clusters. The CFHT has played an important role in this work. Realizing the feasibility of the regime of weak lensing lead to precise calculations of observables in a series of theoretical papers (Blandford et al. 1991; Miralda-Escudé 1991; Kaiser 1992; Bernardeau, van Waerbeke & Mellier 1997; Jain & Seljak 1997; Kaiser 1998). At the same time several groups began to undertake the first analyses of weak lensing in clusters, where the signal remains relatively strong. The availability of these data lead to the development of observational techniques (Kaiser's imcat, for instance), pipelines and data analysis centers (TERAPIX center at IAP) and centers of strength (IfA in Hawaii, IAP in Paris, and CITA in Toronto). These centers have recently advanced weak lensing techniques to a level of maturity where they are now poised to give us precise results for a number of cosmological questions of great interest.
In the past year several groups published analyses of the measurement of weak shear in the field, most of them coming from CFHT. The results indicate that weak lensing is now poised to deliver results on the general properties of mass distribution in the Universe. Three major papers based on CFHT observations have very recently illustrated the potential of cosmological weak lensing analyses:

- Following the first cosmic shear detection with the VIRMOS-DESCART survey (van Waerbeke et al. 2000); van Waerbeke et al. (2001) have published the first tentative to "break the degeneracy" between the amplitude of the dark matter fluctuation spectrum, σ_8, and the density parameter, Ω_M (although some assumptions about other aspects of the mass distribution needed to be made). This result was based on 6.5 square degrees of imaging data. The way is now clear for the next major step which will provide higher order statistics to measure simultaneously σ_8 and Ω_M.

- Hoekstra et al. (2001) using the Red Sequence Cluster Survey (RCS) have for the first time being able to explore the biasing directly from the cross-correlation between the dark matter, measured from weak lensing analysis, and the galaxy distribution, measured from CFH12K optical data. This important work shows that the linear biasing model seems valid on scale ranging from 150 h^{-1} kpc to 3 h^{-1} Mpc. Its amplitude is still a matter of debate, because of the degeneracy between the bias factor and the mass-light cross-correlation coefficient. But recently, the VIRMOS-DESCART survey and the RCS survey joined together and succeeded to address this issue, thanks to the use of these two different samples. It turns out that the biasing seem very close to one (assuming a flat Λ-dominated universe: Hoekstra, van Waerbeke, Gladders, Mellier, Yee in preparation).

- Finally, Pen, van Waerbeke & Mellier (2001) have extracted the E- (lensing) and B- (curl) modes of the weak lensing signal and produced for the first time a direct measurement of the projected power spectrum of the dark matter on scale ranging from 1' to 15'.

These results issued from strong collaborations between Canada (Pen, Hoekstra, Gladders, Yee, van Waerbeke) and France (Mellier, van Waerbeke, Bernardeau, Le Fèvre, Bertin), put CFHT at the forefront of cosmological weak lensing studies. The amount of data and their scientific interpretations are the most important ones obtained so far from any wide field surveys. Moreover, they considerably helped to define next realistic goals and critical limitations for a larger survey.
From a cosmological point of view, the following objectives are envisioned for the CFHLS:

1. Measurement of the projected power spectrum of the dark matter on scale between 30" to < 5 degrees in order to reach the linear angular scales. These scales are still too noisy with present-day surveys (see Pen, van Waerbeke & Mellier 2001) and therefore difficult to interpret without ambiguity in a cosmological context. The goal is to go up to 100 h^{-1} Mpc physical scales (beyond this, systematics are much larger than signal, so this is not a reasonable goal, even by assuming an improvement by a factor of 3 of weak lensing signal extraction).

2. Measurement of the biasing factor with a 5% accuracy on scale ranging from 30" to < 5 degrees. Exploring its dependence with angular scale, galaxy morphology of foreground lenses, and lookback time, in the redshift range $0.1 < z < 0.5$.

3. Measurement of Ω_M and σ_8 with a 10% accuracy from the join use of second and third order statistics on the shear field,

4. Measurement of Ω_Λ, or any dark energy component, from large angular scale cosmic surveys coupled with the CFHLS SNIa surveys and with CMB data.

5. Produce multi-source plane cosmic shear analysis in order to study the evolution of biasing with redshift, to improve by a factor of at least 3 the measurement of skewness of the convergence field and to produce an estimate of the intrinsic ellipticity correlation generated during the merging phase of galaxy halos.

6. Couple XMM surveys, redshift surveys and weak lensing data in order to analyze clusters of galaxies and the physics of both baryonic and non-baryonic dark matter in clusters of galaxies as well as along compact groups located inside large-scale structures.

7. Provide a mass statistic of clusters in the field in order to infer the cluster radial mass profile,

8. Measurement of galaxy halo properties from galaxy-galaxy lensing analysis of 10^7 galaxies.

9. Test alternative to dark matter, like MOND models, from galaxy-galaxy lensing (see Hoeakstra et al. 2001) and cosmic shear studies (see White & Kochanek 2001, who interpreted CFHT results in a MOND context).

These scientific goals are all feasible on a short timescale, as it is demonstrated from present-day results. Most studies will use spectroscopic surveys carried out on 10m-class telescopes, like VIRMOS. The join use of these data sets and of numerical simulations shows that we need to cover 100 deg^2 (effective) in order to reach these goals (van Waerbeke et al. 1999). An important use of the lensing data will be in conjunction with CMB maps from upcoming experiments such as the MAP and Planck satellites. Lensing data gives constraints on the cosmological parameters which are often nearly "orthogonal" to the CMB constraints. Together these will give very high precision measurements of the main parameters, as shown on Figure 2. A particularly interesting possibility is to use the CMB itself as one set of sources and cross-correlate it with the shear detected in the galaxies. This will enable a number of important tests of the assumptions of the analysis.

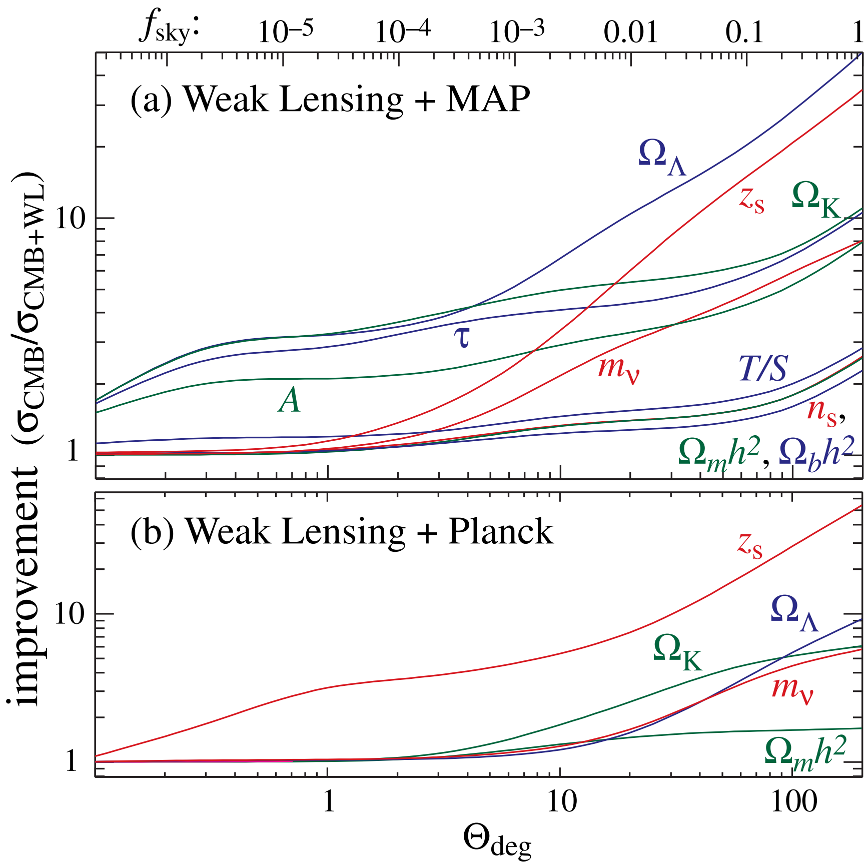

Figure 2: Improving MAP and Planck CMB parameter estimation with weak lensing (Hu and Tegmark, 1999).

3.3.2 Weak Lensing Data Requirements

Weak lensing surveys have been extensively discussed in the published literature. Kaiser and collaborators have been particularly active in advancing the measurement techniques to new levels of precision with phenomenally precise control over PSF variations and other systematics. Mellier's group has done extensive simulation work to derive the survey param-

eters required to make the next generation measurements (see van Waerbeke et al. 1999). Moreover, they have considered in detail many of the known optical aberrations to show that these no longer present a barrier (Erben et al. 2001).
The specifications regarding the design of a weak lensing survey have to take into account the following boundary conditions:
– We know from simulations and real data that we are now able to measure a weak lensing signal of 1% with a 10% relative accuracy for observations with seeing < 0.9", even with optical/atmospheric distortion of 30%. This means that, with better optical design provided by the new prime focus, better image quality provided by queue scheduling and much larger sample, we can definitely get a signal down to 0.3% . The variance of the shear averaged over an angular scale θ can be measured to a 3-σ confidence level down to the following amplitude

$$< \gamma(\theta)^2 >^{1/2} = 0.3\% \ \left[\frac{A_T}{100\ deg^2}\right]^{\frac{1}{4}} \times \left[\frac{\sigma_{\epsilon_{gal}}}{0.4}\right] \times \left[\frac{n}{20\ arcmin^{-2}}\right]^{-\frac{1}{2}} \times \left[\frac{\theta}{10'}\right]^{-\frac{1}{2}} \ , \qquad (2)$$

where A_T is the total sky coverage of the survey, $\sigma_{\epsilon_{gal}}$ the intrinsic dispersion of galaxy ellipticities, n the galaxy number density. The systematics are presently a dominant factor beyond angular scale of 2 degrees. Based on past progresses on PSF anisotropy corrections and on going works within the next five years, we can imagine to reach 10 degrees, but it is very difficult to have clear views whether technical issues will be solved beyond this scale.
– The measurement of the shape of the power spectrum up to 100 h^{-1} Mpc corresponds to angular scales of $\approx$ 5 degrees at $z \approx 0.3$. This is the typical redshift of lenses for surveys with limiting magnitude of $I \approx 25$.
– The contamination by intrinsic correlation of ellipticities mimics weak lensing signal and can be a major source of uncertainties for a shallow survey. Two effects play together to reduce the lensing signal: (1) when the redshifts of sources decrease, the gravitational shear amplitude decreases as well. (2) In deep surveys most galaxies projected along a line of sight are not physically linked. Therefore, the intrinsic correlation of ellipticities produced by tidal torque and angular momentum generation is obviously a small contribution. Conversely, intrinsic correlation increases when the source redshift decreases as for a shallow survey, and may even be a major contribution when source redshift is lower than $z \approx 0.1$.
– Because source clustering may significantly reduce the signal of the skewness (see Hamana et al. 2001), multi-source planes are needed, which implies a need for spectroscopic follow up.
From these conditions, we can now put more quantitative limits on the weak lensing survey. In the following, magnitudes are estimated in the Vega system, and limiting magnitudes are established from our experience on real data, based on the VIRMOS and RCS surveys.

- CFHLS will need to go significantly deeper than $I = 22.5$. Even at this magnitude, the amplitude of the shear is 6 times smaller than what was measured with CFH12K (The shear is weaker because the redshift of galaxies is too low, which decreases the shear signal. With a signal 5 times smaller, the signal reaches an amplitude similar to that of the systematics. Therefore the pure lensing signal extraction and its cosmological interpretation are very difficult.

- Photometric redshifts of very faint sources are not properly calibrated if we go too deep: Beyond $I = 24.3$, there are basically no spectroscopic surveys to calibrate photo-z. This is not acceptable since redshift will be a major input in order to achieve future scientific goals of cosmic shear. The DEEP2 and VIRMOS spectroscopic surveys plan to reach $I = 24.3$ for a large sample of galaxies, so we are very confident that the redshift of sources will be very well known. It would be even better if VIRMOS or DEEP fields were priority targets for the survey.

- When galaxies are too faint, many of them are at very high-z and morphological evolution or merging processes affect the shape of galaxies which may strongly depart from ellipse-like systems. This will considerably increase the noise produced by intrinsic ellipticities of galaxies. It is therefore not recommended to push the weak lensing survey far beyond $z = 1$ for the sources.

- As seen in Equation 2, the survey does need to be of sufficient depth to include a large enough sample of galaxies per solid-angle and lower statistical noise. From present-day surveys 30 galaxies/$arcmin^2$ is a very good target and is achieved if $I = 24.3$. For instance, for the VIRMOS-DESCART survey, the *effective* galaxy number density of the cosmic shear sample (after masking and removing close-pairs and masking which reduce by 30% the galaxy density) is 20 galaxies/$arcmin^2$. The average redshift will be about 0.8, so we are also not concerned by morphological evolution.

The absolute minimal requirement for the next step in lensing measurements is to obtain 100 square degrees of weak lensing field in patches of at least 5×5 degrees. Because of cosmic variance, it is important to spread the surveys over uncorrelated patches. The minimum is 4 patches. As far as the total area is conserved, 3 patches will be marginally acceptable. The unavoidable problem of very bright stars means that some of the area is lost. For example, in the VIRMOS-DESCART survey, about 30% of the total area has to be masked in order to avoid bright stars, comet-like patterns, noisy boundaries of CCDs. This leads to functional minimal requirement of 130 square degrees in patches of 6×6 square degrees in order to get an *effective* area of 100 square degrees.
$I = 24.3$ **with seeing** < 0.9" **over 4 patches covering 130 deg^2 is therefore the minimum required for the weak lensing component of the CFHLS.** In addition, we need u*g'r'z' and at least K band for photometric redshift. Since the XMM field is unique and has a great potential for clusters of galaxies, baryonic vs. non-baryonic matter, we also recommend to carry out a complete follow up of the XMM field, extending the $6^o \times 6^o$ XMM field to $10^o \times 10^o$. From a cosmic shear point of view, this field would allow to evaluate the power spectrum up to 10 degrees. See below for more on this $10^o \times 10^o$ field.
It is not reasonable to imagine having spectroscopic redshifts for all galaxies up to $I = 24.3$ in 130 square degrees. But on the other hand, studies of weak distorted galaxies and dark matter halos with look back time is an important goal for this survey. In addition, numerical simulations done by Hamana et al. (2001) demonstrate that clustering of galaxies significantly affect the measurement of the skewness (by 10 to 30%). So it is absolutely necessary to get photometric redshift for all galaxies without spectroscopic redshift. Therefore, the survey location definitely needs to cover area where massive spectroscopic follow up are

planed in order to calibrate and check photo-z.
With the expected redshift distribution of the weak lensing sample ($I = 24.3$, Vega system), an unambiguous determination of redshift is not possible without photometric data in all MegaCam filters, including z'. Even in this optimal condition, K (or H data) are also important and will be necessary. In order to get photo-z for at least 60% of the I-band selected sample, we studied in collaboration with R. Pelló the magnitude range of an i'-limited sample of galaxies up to $I = 24.3$. The comparison of CFH12k and MegaCam red filters translates in

$$i' \simeq I + 0.2 \ . \tag{3}$$

Using simulation models of galaxies based on Charlot-Bruzual's modeling and the GISSEL spectral library, we then inferred the limiting magnitudes in each MegaCam filter which guarantees at least 50% of the i' sample is also observed (with $5\sigma3$") in all filters and more than 70% is observed in $u*$ g', r', i' (same detection limits):

$$u* = 24.5, \quad g' = 25.5, \quad r' = 24.7, \quad \text{and} \quad z' = 23.0 \ . \tag{4}$$

We can now make an estimation of exposure times based on expected performances of MegaPrime and on previous experiences with CFH12K: using real data (the Canadian Red-sequence Cluster Survey and the VIRMOS survey) we can predict with a good accuracy the expected exposure time in z' and i': with VIRMOS, based on 20 nights integrating all problems (including seeing variation, absorption, etc...), $I = 24.3$ is obtained in 3600 sec. Likewise, with the RCS, $z' = 22.7$ is obtained in 3600 s with the CFH12K (both for $5\sigma3$" on extended object).

A comparison of the CFH12K and MegaCam throughputs and a computation based on the MegaCam performances provided by CFHT have been performed and cross-checked by R. Pelló. We finally estimated the performances of MegaPrime in order to reach $i' = 24.5$ ($I = 24.3$) for an extended object, a seeing of 0.8" and for 5σ detection in a 3" aperture as follows:

- u*=24.5 in t_{u*}=6000 sec., g'=25.5 in $t_{g'}$=2500 sec., - r'=24.7 in $t_{r'}$=2000 sec.,
- i'=24.5 in $t_{i'}$=4300 sec., -z'=23.0 in $t_{z'}$=7200 sec.

It is important to stress that this strategy is defined assuming that the weak lensing survey will be done in i'. This is the most suitable observing mode because the spectroscopic samples are based on I-band selected sample of galaxies. However, if the fringe residuals are too strong, or if the r' filter is more appropriate for other scientific goals, then the r' filter is an acceptable alternative.

For all filters, but the i'-band (or the one primary used for weak lensing analysis), median and worse seeing (provided it does not go beyond about 1.0 arcsecond) is acceptable. Therefore, assuming 3 6×6 + 1 10×10 patches, the minimal function time request for this program is 1271 hrs. or 196 nights of 6.5 hours. It should be noted that the individual 1×1 fields covered by the mosaic need to be overlapped to build the patches. The resulting area of these patches will be $\approx 10\%$ smaller.

Published

Telescope	Pointings	Total Area deg^2	Lim. Mag.	Ref.
CFHT	5 × 30' ×30'	1.7	I=24.	van Waerbeke et al. 2000
CTIO	3 × 40' ×40'	1.5	R=26.	Wittman et al. 2000
WHT	14 × 8' ×15'	0.5	R=24.	Bacon et al. 2001
CFHT	6 × 30' ×30'	1.0	I=24.	Kaiser et al. 2000
VLT/UT1	50 × 7' ×7'	0.6 d	I=24.	Maoli et al. 2001
HST/WFPC2	1 × 4' ×42'	0.05	I=27.	Rhodes et al. 2001
CFHT	4 × 120' ×120'	6.5	I=24.	van Waerbeke et al. 2001
HST/STIS	121 × 1' ×1'	0.05	V$\approx$ 26	Haemmerle et al. 2001
CFHT	10 × 126' ×140'	16.	R=22.5	Hoekstra et al. 2001
CFHT	4 × 120' ×120'	8.5	I=24.	Pen et al. 2001

Projects

Telescope	Pointings	Total Area deg^2	Lim. Mag.	Expected completion
RCS	10 patches	50	R=22.5	2003
WFI	4 patches	10	R=23.	2002-2003
NOAO+CTIO	?	9	R=25.	2003
SUBARU	?	100	R=25.	?
VISTA	?	200-1000	R=25.	> 2009
CFHLS	4 patches	210	I=24.	2007

Table 2: Present status of cosmic shear surveys with published results followed by new projects (new-ref). Magnitudes are for extended objects.

Is this weak-lensing component of the CFHLS self-consistent? Regarding weak lensing, near infra-red observations will be absolutely necessary *only* for the impact of clustering in the skewness... Otherwise, the averaged redshift of the sample will be known well enough to allow the CFHLS to produce outstanding results by itself.

Figure 3 places the CFHLS wide synoptic survey among the other surveys already completed, ongoing or planned. Table 2 gives the status of various cosmic shear surveys.

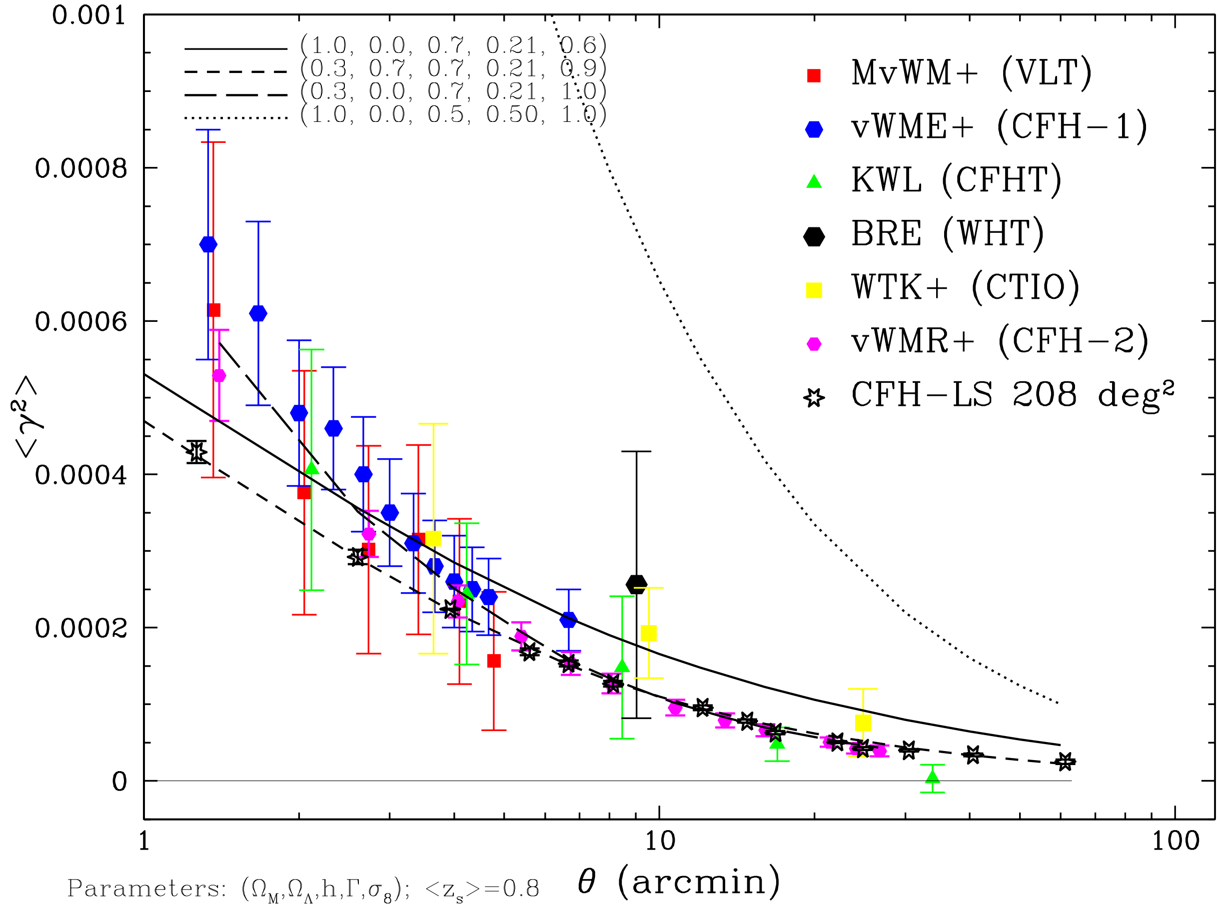

Figure 3: Top hat variance of shear as function of angular scale from 6 cosmic shear surveys. The CFHLS (open black stars) illustrates the expected signal from a large survey covering 200 deg^2. For most points the errors are smaller than the stars.

- MvWM: Maoli, van Waerbeke, Mellier et al. 2001 - vWME: van Waerbeke, Mellier, Erben et al. 2000 - KWL: Kaiser, Wilson and Luppino 2000 - BRE: Bacon, Refregier and Ellis 2001 - WTK: Wittman, Tyson, Kirkman et al. 2000 - vWMR: van Waerbeke, Mellier, Radovich et al. 2001

3.4 Large-scale clustering evolution from the CFHLS galaxy and cluster catalogues

3.4.1 Context

Over the past 20 years, our knowledge of the large-scale clustering of galaxies has improved drastically, through the systematic measurement of redshifts for galaxies selected from large photometric surveys. By providing a multi-band catalogue with excellent image, photometric, and astrometric quality, the CFHLS "Wide Synoptic" survey will be a reference database for studying the evolution of the large-scale clustering. Several analyses will be performed from the photometric multi-band data only, but the finer and outstanding results will require the measurement of photometric redshifts for the detected galaxies, making a strong case for the 5-band u*g'r'i'z' observations.

The results on large-scale clustering which have attracted attention in the past two decades address fundamental issues in the study of the distribution of matter in the Universe. Wide-angle nearby redshift surveys have shown that galaxy clustering exists on scale up to $\sim 100h^{-1}$ Mpc, and is dominated by high contrast and anisotropic structures (de Lapparent, Geller and Huchra 1986; da Costa *et al.* 1994; Shectman *et al.* 1996), among which the so-called "Great Wall" (Geller and Huchra 1989). The large-scale galaxy distribution detected in these surveys can be quantitatively characterized by an alternation of sheet-like structures and voids (Schmalzing and Diaferio 2000; El-Ad and Piran 1997). On scales larger than $20h^{-1}$ Mpc, the distribution is consistent with the sponge-like topology expected from random phase Gaussian initial perturbations, whereas on scales smaller than $10h^{-1}$ Mpc, the observed distribution shows more coherence than random phases (Vogeley *et al.* 1994). Similar high-contrast structures were detected out to redshift $z = 0.5$ (Bellanger and de Lapparent 1995; Small *et al.* 1999), but have not allowed topological analyses due to the limited volumes sampled.

Super-clusters extending over several $100h^{-1}$ Mpc are detected in the distribution of clusters of galaxies (Tully *et al.* 1992; Kalinkov and Kuneva 1995). As they efficiently probe large volumes, clusters of galaxies are the best tools to probe the largest scales of the galaxy distribution, and X-Ray selected catalogues (ROSAT) provide reliable samples for quantitative analyses. The correlation function of the REFLEX clusters with $z \lesssim 0.3$ shows a correlation length of $\sim 20h^{-1}$ Mpc and crosses zero at $\sim 45h^{-1}$ Mpc (Collins *et al.* 2000). Higher-order moments of the distribution confirm the existence of non-gaussian features in the large-scale structure traced by clusters (Kerscher *et al.* 2001). Moreover, the power-spectrum of the REFLEX clusters shows that there is power up to scales $k \sim 0.02\ h\mathrm{Mpc}^{-1}$, with a flattening of the power-law at $k \sim 0.05\ h\mathrm{Mpc}^{-1}$ (Schuecker *et al.* 2001). These results are confirmed by the power-spectrum analysis of the partial 2dF galaxy survey, which favors models containing baryon oscillations (Percival *et al.* 2001). Probing comparable scales (i.e. $\lambda \sim 300h^{-1}$Mpc) at $z \sim 1$ is thus a challenging and compelling science case for the "Wide Synoptic" survey of the CFHLS.

In the following sub-sections, we show how the galaxies and clusters selected in the $10^\circ \times 10^\circ$

of the "Wide Synoptic" survey (supplemented by the galaxies from the 3 $6° \times 6°$ patches) will provide new constraints on galaxy evolution at $z \sim 1$ and on the allowed range of cosmological parameters, from complementary approaches to the other projects proposed in the present document.

3.4.2 The cluster catalogue

Thanks to its unprecedented combination of area and depth, the Large $10° \times 10°$ Patch of the "Wide Synoptic" Survey will form the basis of the CFHLS galaxy and cluster large-scale structure studies. The field reaches a comoving transverse size of $\sim 400h^{-1}$ Mpc at $z = 1$ (for $\Omega_m = 0.3, \Omega_\lambda = 0.7$); this is a crucial scale range at high redshift, without equivalent so far. The galaxy and cluster catalogues to be extracted from the area will constitute a unique reference data set for the next decade. For this, we require that images are " simultaneously" obtained in at least 4 bands (g', r', i', z') in order to achieve usable photometric redshift accuracy ($\sigma_z \lesssim 0.25$ (Pelló *et al.* 2001)). This will subsequently allow us to apply "matched filter" techniques in combination with spatial clustering analysis to detect the galaxy clusters. In the Large Patch, we expect more than 2 millions galaxies. The predicted number counts for clusters are given in the Table below for various cosmological models, assuming standard hierarchical structure formation scenarios (following Refregier, Valtchanov & Pierre 2001).

Model	$0 < z < 0.5$	$0.5 < z < 1$	$1 < z < 1.5$
τCDM	160	60	0
ΛCDM	370	600	50
OCDM	360	860	210

Table 3: Predicted cluster counts in the 100 sq.deg. CFHLS Large Patch

The cluster number counts depend strongly on the matter density, consequently the CFHLS cluster data set will allow us to constrain Ω_m with a very good accuracy (see next Section). The Large Patch will include the $8° \times 8°$ equatorial field to be covered by the XMM Large Scale Structure Survey (XMM-LSS, of which 10 sq.deg. will also be observed by the SWIRE SIRTF Legacy Program). In this region, all clusters will be spectroscopically identified. This will provide not only redshifts for more than half of the CFLHS clusters (with about 10 z per cluster) but also a most important synergy between optical and X-ray cluster detection procedures. (Note that the XMM-LSS will be detecting much more easily $z < 1$ small groups as well as clusters out to $z \sim 2$, since as any X-ray survey, it is free of projection effects). Completing the spectroscopic identification of all the some 1000 Large Patch clusters is within the capabilities of the (northern and southern) 8 m class telescopes, to which the CFH community has access. We shall perform detailed analysis of the optical properties of selected clusters and groups of galaxies (e.g. luminosity function, spectral type content.) In addition, the associated XMM-LSS multi-wavelength follow-up in the optical/X-ray/radio/infrared domains promises to be extremely rich (cf XMM-LSS home page: http://vela.astro.ulg.ac.be/themes/spatial/xmm/LSS /index_e.html and Pierre 2001). These will be of great relevance for understanding the relationship between the dark matter distribution traced by the weak shear analysis and the clustering of objects with various density thresholds (from galaxies to small groups and to rich clusters of galaxies) as well with AGN and obscured objects detected in the SIRTF associated survey. It will be also of prime interest to link the cluster optical properties with those obtained from the XMM data, extending existing studies to much higher redshifts. Also, the spectroscopic information will allow us to estimate velocity dispersions and masses, and to compare these quantities with the values predicted from the X-ray luminosity. Finally, photometric redshifts could reveal the optical counterparts of the filaments predicted by Cold Dark Matter scenarios, which may be observed in subsequent XMM very deep pointings (Pierre, Bryan & Gastaud 2000).

3.4.3 Cosmology with the cluster sample

As clusters of galaxies represent the deepest potential wells of the universe, these systems deserve a special attention. The cluster catalogue supplemented with spectroscopic redshifts will allow unique analyses of the 3D clustering and of its topological properties. In particular, it will provide, for the first time, the correlation function of galaxy clusters in two redshift bins ($0 < z < 0.5$ and $0.5 < z < 1$) and the measurement of redshift/space distortions. The evolution (or no-evolution) of the cluster-cluster correlation function with redshift provides a test of both the bias model for halos and for the gravitational instability paradigm. Moreover, combining cluster Large Scale Structure studies and cluster number counts evolution is of great relevance for cosmology. This provides an independent check of the cosmological parameter values determined from the Cosmic-Microwave-Background measurements and from the supernova studies, as they do not rely on the same physical processes. This will allow us to break the degeneracy between the shape of the power spectrum and the value of the matter density. Below, we show the constrains on cosmological parameters expected from the CFHLS Large Patch clusters for a ΛCDM model.

Because this optical/X-ray study will be performed in the same area of the sky as the weak-lensing analysis, it will allow a unique and comprehensive understanding of mechanisms (and of the corresponding systematics) by which luminous matter may be biased with respect to the dark matter, on scales which have never been investigated so far in the high redshift universe. It will also be very instructive to compare the cosmological parameter values determined by both approaches, and calibrate systematics which may arise in the lensing analysis over very large areas.

3.4.4 The galaxy luminosity function

The luminosity function of galaxies is an essential tool to relate the spectrum of primordial fluctuations in the matter field with the history of individual galaxies in terms of interactions, mergers, and star formation. It has been established in the local Universe that the luminosity function is a composite of intrinsic functions characterizing each morphological type of galaxies (Binggeli, Sandage and Tammann 1988); the full "galaxy luminosity distribution" can only be described by detailed knowledge of the intrinsic luminosity functions and the relative proportions of the different galaxy types in the various environments. The existing measures of the luminosity function at $z \gtrsim 0.5$ from redshift surveys (with $\sigma_z \lesssim 0.001$) provide varying results, which are a function of the selection criteria of the samples (Lilly

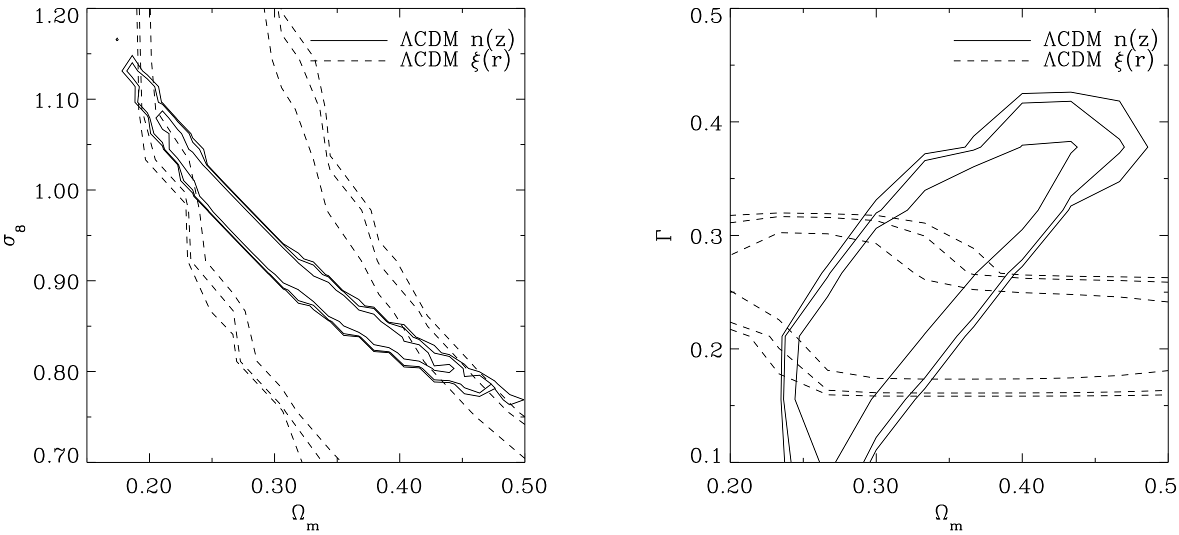

Figure 4: Cosmological constraints from the CFHLS Large Patch clusters
Left: Constraints upon the cosmological parameters Ω_m and σ_8 (the amplitude of mass fluctuations on 8 h^{-1} Mpc scale) for a ΛCDM universe obtained from cluster counts (solid lines) and correlation function (dashed lines). In each case, the 68%, 90% and 95% confidence level contours are shown along with the assumed model (cross). Cluster abundance data provide strong constraints upon the $\Omega_m - \sigma_8$ combination.
Right: Constraints upon the cosmological parameters Γ (the shape of the power spectrum) and Ω_m for a ΛCDM universe (symbols as defined in **Left**). The correlation function is a powerful tool to constrain the shape of the initial spectrum. These calculations have been performed assuming that only the redshifts over the $[0 < z < 1] \times [100 \text{ deg}^2]$ volume are available.

et al. 1995; Heyl *et al.* 1997; Lin *et al.* 1999; de Lapparent *et al.* 2001): significant evolution in the luminosity function of the late-type galaxies is detected, which causes an increase of the luminosity density by a factor 2 between $z \sim 0$ and $z \simeq 0.5$, but the nature of this evolution has not yet found a common agreement.

Once the CFHLS is completed in the 5 u*g'r'i'z' bands, combination of the excellent CFHT image quality with photometric redshifts (Pelló *et al.* 2001) will allow us to calculate, with a high signal-to-noise ratio, the intrinsic luminosity functions as a function of morphological type. Analyses of the Hubble Deep field have shown that evolution in the luminosity function *can* be measured using photometric redshifts (Sawicky, Lin and Yee 1997;Takeuchi, Yoshikawa and Ishii 2000). Knowledge of the intrinsic luminosity functions will also allow finer analyses of the galaxy number-counts. Their modeling at optical magnitudes fainter than 23 suffers from an intrinsic degeneracy between the cosmological parameters and the scenarii for galaxy evolution (Pozzeti, Bruzual, and Zamorani 1996). With realistic models of the evolution of the galaxies (in terms of number and/or luminosity evolution), the number-counts will put direct constraint on the cosmological parameters.

3.4.5 Evolution in the projected clustering of galaxies

The two-point angular correlation function The evolution of the angular correlation function remains poorly known beyond $I \sim 24$: at magnitudes $I \gtrsim 24$, only 3 surveys provide measures which differ by a factor ~ 4 in amplitude (Brainerd and Smail 1998; McCracken *et al.* 2000; McCracken *et al.* 2001). The largest of these samples covers a total area of ~ 1 deg^2 at $I_{AB} \lesssim 25$, split into 4 patches of ~ 0.25 deg^2 (McCracken *et al.* 2001: the Canada-France Deep Fields, based on CFHT observations). Even at brighter magnitudes, the analyses of the different surveys yield controversial results (see Fig. 5). The deepest and largest patch observed up to now is a 16 deg^2 area to $I < 24$ obtained by Postman *et al.* (1998). The authors claim that they observe both a flattening of the correlation amplitude beyond $I \gtrsim 22$ and some flattening of the slope of the power-law. Both results favor a slight clustering evolution compatible with the current hierarchical clustering models. Although the flattening of the slope has been confirmed by McCracken *et al.* (2001), these recent observations show no evidence of a flattening of the amplitude. The flattening of the amplitude still needs confirmation, as no other analysis measured a similar trend (see Figure 14 of McCracken *et al.* 2001).

The $10° \times 10°$ and $6° \times 6°$ patches of the CFHLS "Wide Synoptic" survey will provide the finest analyses of galaxy angular correlations ever done with such a combination of large area and depth ($r' = 25.7$). These analyses can be conducted from the multi-color data, before calculation of the photometric redshifts is performed. The high signal-to-noise in the measurement of the angular correlation of galaxies expected from the 4 patches of the "Wide Synoptic" survey should resolve the present controversy and disentangle the true evolutionary effects from possible photometric systematic errors and the effects of cosmic variance. In addition, these data will provide the deepest angular correlation measurements of color selected samples. Recent analyses (Cabanac *et al.* 2000; McCraken *et al.* 2001) show systematic differences in the amplitude of correlation as a function of galaxy color. These different clustering properties of the various galaxy populations were already known for the nearby galaxies from the morphology density relationship (Dressler 1980), but detailed characterization of the behavior out to redshifts $z \sim 1$ is still needed.

Once the photometric redshifts are available for the "Wide Synoptic" survey (Pelló *et al.* 2001), it will be possible to further analyze the angular correlation measurements. The luminosity functions will allow detailed modeling of galaxy evolution out to $z \lesssim 1$. The variations of the amplitude of the angular correlation will then put *direct* constraints on the cosmological parameters. Another unique opportunity of the CFHLS galaxy survey will be to measure *directly* the evolution of the angular correlation function with redshift out to $z \sim 1$. So far, interpretation of the evolution of galaxy clustering is based on a priori choices of the luminosity functions for each galaxy class considered, which in turn provide the redshift distribution for each class. Measurement of photometric redshifts for the large number of galaxies with $z \lesssim 1$ contained in each patch will allow the calculation of the angular correlation function for several sub-samples in redshift. It will then be possible to disentangle the true evolutionary effects in the large-scale clustering from number and/or luminosity evolution of the different galaxy populations.

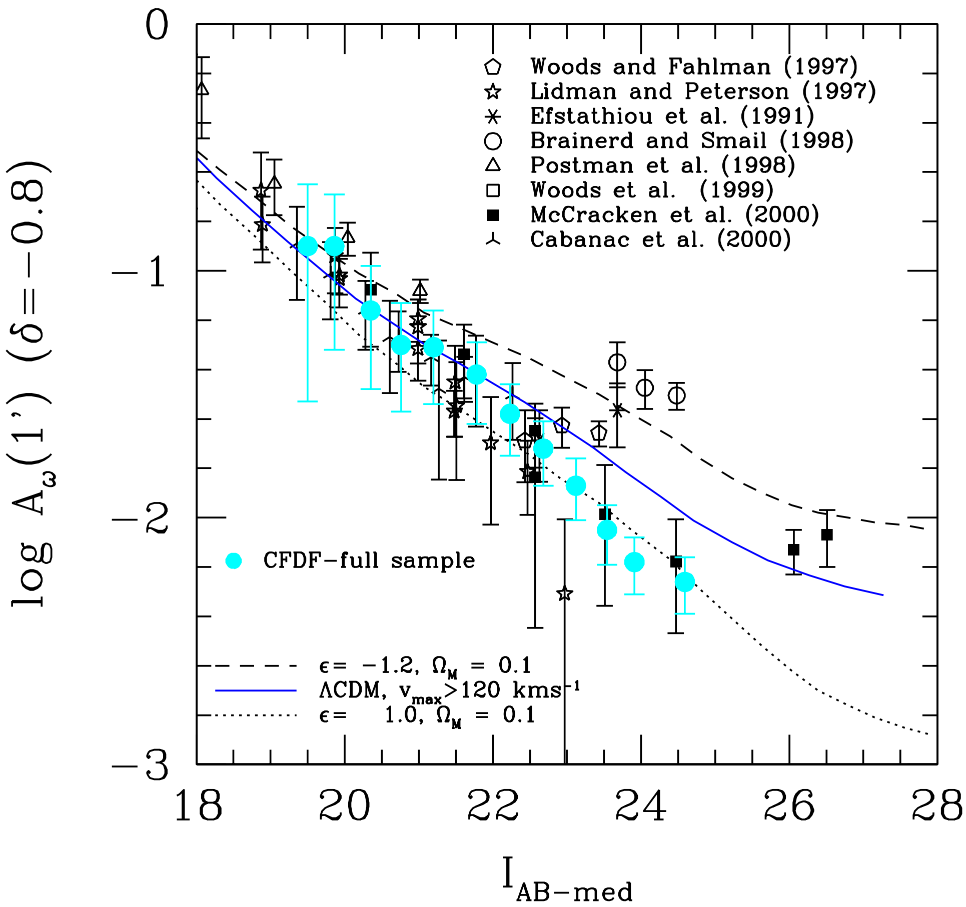

Figure 5: The decrease of the amplitude of angular correlation for the recent measurements (from McCracken et al. 2001). The flattening of the amplitude is controversial and remains to be confirmed by larger surveys.

High-order statistics Thanks to the angular positions of about 2 million galaxies, high-order projected statistics of the galaxy distribution will be measured with an unprecedented accuracy. Presently, estimates from the analysis of the exiting galaxy catalogues reach at best the sixth order up to scales of $20h^{-1}$ Mpc, and the results do not agree for statistics of order 3 and higher (Szapudi and Gatzanaga 1998, for the APM and EDGSC catalogs, Bouchet *et al.* 1993 for IRAS , Benoist *et al.* 1999 for SSRS2). In contrast, the "Wide Synoptic Survey" will allow the reliable calculation of high order statistics up to order 6 and for scales as large as $100h^{-1}$Mpc, thus reaching the domain where structure growth is still in the linear regime. The high-order moments can then be used as powerful tools to test the hypothesis of the Gaussian nature of the initial density fluctuations (Chodorowski and Bouchet 1996). Even in the case of an initial gaussian distribution, non-gaussianity at small scales is induced by gravity and the determination of the high-order moments (skewness and kurtosis for instance) and their evolution with time will allow us to put constraints on the slope of the fluctuation spectrum (Juszkiewicz *et al.* 1993). This will ultimately provide a test for the validity of the hierarchical ansatz (Balian and Schaeffer 19893) on the widest angular and time scales ever investigated.

3.4.6 The relative clustering of QSOs and galaxies

The distribution of QSOs among the galaxies is poorly known, as it is difficult to obtain a homogeneous sample of galaxies and QSOs in a common volume which is large enough to allow statistically significant measurements. The observing strategies usually favor deep imaging in the vicinity of QSOs, but this only provides a partial view whose interpretation is tied to the assumptions on the unknown sample of field galaxies. One of the issues is whether QSOs are more often present in galaxy clusters and groups than in isolated regions of the field. Brown, Boyle and Webster (2001) recently confirmed the associations of Active Galactic Nuclei (AGNs) with other galaxies: they measured from photographic plates a strong angular correlation between the 69 identified AGNs (36 QSOs and 33 Seyfert galaxies) and red galaxies assumed to be giant ellipticals, which are in addition the most clustered objects; in contrast they measure a low correlation between AGNs and blue galaxies. The CFHLS combines three desirable characteristics which make it unique for QSOs-galaxy clustering analysis: depth, multi-color photometry and large area. Multi-color photometry will allow a robust selection of QSOs from the multi-color space and a measure of their photometric redshifts. The "Wide Synoptic" survey will provide a few thousand QSOs (10^4 in the "Deep Synoptic" survey) and an order of magnitude more galaxies, leading to the largest complete samples of this kind available for QSOs-galaxy clustering studies. From these samples, one can expect a pioneering description of the clustering of QSOs among galaxies.

3.5 The cosmic equation of state

Over the past year there has been a profound shift in our view of the cosmological world model as a result of the two supernovae teams finding that the distance-redshift data is best described by an "accelerating" universe, as described by a flat low density model. The more recent Boomerang and Maxima results find that the first Doppler peak is at a location that indicates that the universe is flat. The implication of these results is that the mass energy of the universe is dominated by a repulsive Λ. The effects of this non-clustering mass energy are only readily visible on the scales of the universe itself. Therefore its properties are only open to ready investigation through astronomical investigation.

One important property of Λ is the relation between its energy density, ρ_X, and its effective pressure in the cosmological equation, $p_X = w\rho_X$. A constant Λ has $w = -1$. At this stage most theorists would prefer some dynamical form of Λ which varies in time. There is a huge range of alternatives arising from string theory, "quintessence" and other fundamental theories of fields. Quintessence predicts a late-time value of $w \simeq -0.8$ and one form of strings predicts $w = -1/3$. Values that are currently discussed (see Albrecht and Weller, 2000) cover the range from about -1.1 to -0.5. It must be emphasized that at this stage there is no useful constraint in this range.

A group has proposed that a specialized satellite, SNAP, be built to provide a very tight constraint on w (see snap.lbl.gov). As proposed, this is approximately a 2.5m (HST sized) telescope with a 1 degree optical imager, an IR imager, and a low resolution spectrograph. They suggest that this could begin observations in about 2006, based on very prompt approval and minimal complications. We expect to be able to publish our primary results before they begin observing. There is considerable value in ground based studies undertaking the first measurement of w which will also lead to huge expansion in our knowledge of SnIa prior to the launch of SNAP through the creation of a large, uniform and "clean" sample which is likely to be invaluable for further measurements of the time variation of w.

At this time CFHT has been proven to be the best existing telescope to find SnIa and MegaPrime will improve that situation. Below we lay out a proposal to make a measurement of w. As much as possible we try to take a balanced approach to this issue to help understand the evidence that we have assembled showing that the basic approach will work. Note that we will create a well-sampled dataset of about 2000 SnIa (and a comparable number of SnII) which exceeds anything else available, even that of the first round SNAP plans. All of the photometry for these will be in our data and we hope and expect that we will learn techniques which will allow us to incorporate these into our analysis to allow a new level of precision in the measurement.

The funding status of SNAP is not clear at the moment. The CFHLS is likely to obtain very important results which could later be nicely refined by SNAP, would the SNAP project be completed, in a very complementary way, as SNAP is going to look at SnIa with much higher z than CFHLS.

3.5.1 2000 CFHT Supernovae and w

It has now been established that within the precision of the data SnIa can be calibrated to yield their luminosity. The discovery of the luminosity-decline relation is the key ingredient. Normally every supernovae discovered must have its spectrum measured to confirm that it is a Ia. In the case of this program we expect to discover nearly 400 Ia per year out to redshift about 1. Based on the discovery redshift distribution, we estimate that the spectroscopic follow-up would require approximately 3 nights of 8m class telescope time per month, or about 30 per year to follow two campaigns five months long. Between Canada and France we have access to the 4 VLTs, 2 Gemini and 2 Magellan. However, since all confident supernovae detections will be immediately available on the web we expect informally collaboration will allow us to acquire the necessary spectra. Furthermore, we are cautiously optimistic that the 200,000 uniform photometric measures we will acquire will allow us to devise new, entirely photometric, approaches to typing as well control over as-yet unknown systematic errors.

There are two proposed survey styles. The common element is to observe every second night if image quality is better than 85%, currently 1 arcsec. The French group proposes to observe 300, 600, 1800 and 1800 sec in g', r', i' and z' respectively. The Canadian group proposes to use 900, 1800, 3600 and 1800 seconds in the same filters. The total cost in queue time per epoch is either 1.25 hours and 2.25 hours. The shorter integrations are less costly and produce similar errors provided that the "intrinsic dispersion" in Ia brightness is at least 0.1 mag. The longer integrations have the significant advantage that, for as much as is known of the Ia luminosity function at peak, we will be more than 50% complete in all colors up to redshift 0.9, as shown on Figure 6.

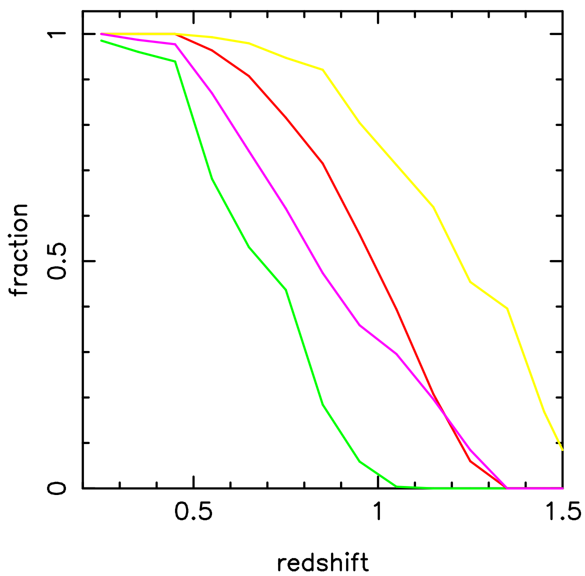

Figure 6: Percentage completeness at peak brightness versus redshift in the g', r', i' and z' bands (from left to right at 0.5). The survey will be 50% complete to redshift 0.9 in the bands used to measure color around peak brightness. This fixes the integration time for a single epoch and is central to the design of the survey.

We assume that the camera will be on the telescope long enough to allow 5 month campaigns one each field per year (this may not be true, in which case the integration time is automatically reduced–there is no real value in observing more often than once every two days). Consequently the total integration times in u*, g', r', i' and z' will be approximately 33, 33, 66, 132 and 66 hours per field, respectively. This meets our goal of obtaining "near HDF" depths. We should hit near to 28.4 (Vega) in g', 28.0 in r', 27.8 in i' and 26.0 in z', assuming $\sqrt{T}$ improvement (all Vega).

3.5.2 Details of Survey Design

The three key ingredients to designing the survey are the estimated limited magnitude of MegaPrime in the SDSS filters, real-world sky statistics of clear sky, seeing and transparency for Mauna Kea, and the current best-estimates of supernovae rates, luminosity functions and light curves as observed in the SDSS filters. We have used a set of programs kindly provided by John Tonry (2001). It should be emphasized that some of the numbers used in this program are controversial at the factor of 50% or so level. However, it does represent the state of knowledge in this field at this time. The same sky series were used by the French and Canadians. The French used their estimate of supernovae rates and luminosities whereas the Canadians used values from Tonry (2001). For the same assumptions the two teams derived very similar results. The precision of w measurement, with an Ω_m estimate from weak lensing, should be about 5%. The strategic difference between the two approaches is based on whether photometry in all bands near peak light is sufficiently important to roughly double the observing time. The strategy supported by the MSWG and outlined in the previous subsection is based on the Canadian approach which allows the best possible control over systematics and at the same time satisfies the goals of the ultra deep survey.

3.5.3 Primary Scientific results

In total this program will produce about 2000 SNIa and comparable numbers of SNII. The 10% subsample in E/S0 gives $\sigma_w = 0.18$ if we use the readily available constraint on Ω_M from weak lensing. If we add constraints on both Ω_M and Ω_Λ from CMB then $\sigma_w \simeq 0.07$. Moreover this vast dataset will be extensively examined for systematic errors at a new level of precision. The other 90% of the SNIa sample will likely be able to be eventually turned into a precision distance estimator sample as well. If so, then we get a result that is $\sigma_w \simeq 0.03 - 0.05$, within a factor of two to three of what can be done with SNAP.

3.5.4 Data Requirements

We require that the seeing be better than 85 percentile image quality, currently one arcsecond, but this should improve to about 0.9 arcsecond with MegaPrime. We require observations every second night, provided that the sky is clear and the image quality is met. If these are not true, then the observations are not taken (thereby being a good time for calibrations, if photometric). Ideally we request first and last nights of the dark run at 95 percentile seeing and the six intervening nights at 85 percentile seeing. Statistically, allowing for 75% cloudy weather (the simulator allows for night-to-night correlations) this amounts

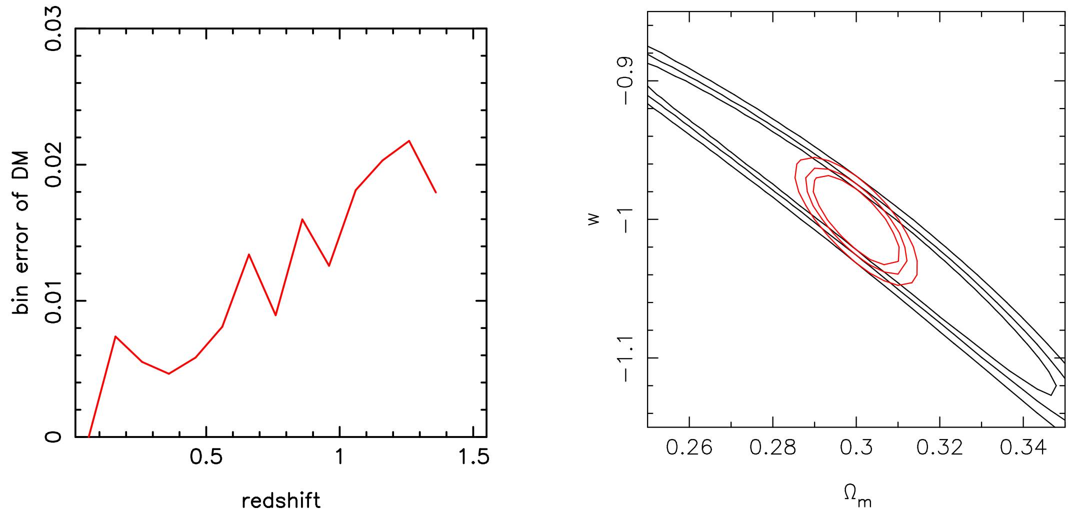

Figure 7: *Left:* Error versus redshift, in bins of delta z=0.1 for the entire CFHLS supernova sample over five years. There are 100 to 200 supernovae per redshift bin, so the error per supernova is roughly ten times greater. *Right:* 68, 90 and 99% confidence intervals in the Ω_m vs. w plane for the CFHLS. The large ellipses are from the supernovae by themselves. The smaller contours are the combination of the supernovae and the weak lensing value of Ω_m. *See the Appendix for similar graphs based on different simulations.*

to a request of about 5.25 epochs per month. For 5 month campaigns over five years this is 131.25 epochs. For four fields with a total of 2.5 hours of open shutter time this is 1312.5 hours, or 202 queue nights.

3.5.5 Complementary observations

The groups interested in Ia would probably want to pursue follow-up imaging in the JHK bands during bright time for high redshift supernovae through PI proposals or as part of a CFH survey organized with Wircam.

3.5.6 Auxiliary Uses

The entire 4 patches will have time sampling ranging from about 10 minutes to a few hours, to roughly a day, to 5 years. This should uncover a vast number of variable stars, faint ecliptic objects, moving galactic stars, and cosmological variables such as QSO's at no additional cost.

3.6 Galaxy Evolution - Star Formation History - AGN environments

3.6.1 Context

The study of galaxy formation and evolution requires the multi-color energy distributions (SED) for galaxy populations of any type as well as a detailed and comprehensive mapping of the structures up to the most distant objects attainable. The galaxy formation models such as semi-analytic models in hierarchical structures dominated by CDM cosmological models has led a large number of predictions on the distribution of galaxies in mass and luminosity (luminosity function, bias factor), or in position (clustering, correlation function). These predictions are not systematically in agreement with observations and still need to be tested on large scales and at high redshift as few data are presently available for such an extensive study. As an example, the deepest multi-color imaging data obtained so far are the Hubble Deep Fields (North and South). This multi-color dataset has triggered a large number of investigations of prime interest to test the models of galaxy evolution. It was also interpreted with so-called "monolithic" models of evolution which are not predicted by CDM models (see Figure 8 which presents an interpretation of faint galaxy counts up to the depth of the Hubble Deep Field North). Moreover, the study of Lyman-break galaxies at redshifts larger than 3 in terms of morphology and spectral content allowed to start to draw a global scheme of how galaxies formed and evolved in the cosmological context.

One essential objective of a deep survey with a multi-color photometry over a wide wavelength range is to understand the formation of galaxies and their relation with AGN environments and proto-structure. It will also give access to an accurate information on galaxy morphologies. Associated to a distance measurement through a photometric redshift, morphology and color distribution simultaneously give signatures of galaxy evolution by types. For illustration, two theories presently match the formation of elliptical galaxies: a "monolithic" dissipative collapse at the most earliest epochs ($z > 5$) and a hierarchical merging of two massive spirals at $z \simeq 1$. Morphological information could disentangle these theories. The role of AGNs localized in clusters or proto-clusters may also be related to the population of central elliptical galaxies in these same structures.

Another objective is to estimate the star formation rates of various galaxy populations, at depths never reached before. The global star formation history (see the example of the results of the Canada-France Redshift Survey) is dominated by spirals at redshifts $z < 1$ and ellipticals at redshifts $z > 1$. The deep survey of the CFHLS will allow to confirm and to improve this debated determination at high redshifts. In particular, the deep survey in the $u^\star$ band which samples the galaxy emission from the recent massive star population will be crucial to measure activity of star formation at distant redshifts. The most refined techniques used to build codes of photometric redshifts which allow accurate estimates in most redshift ranges, while the spectrophotometric (or color) models of galaxy evolution will be compared to the data, for a measure of the young and old populations, *i.e.* the global star formation history.

The final objective, essential from a large scale camera, is the possibility to study the environments of active nuclei, quasars or radio galaxies. The optical counterparts of the distant radio sources show evidences of stellar signatures at the highest redshifts. The galaxy

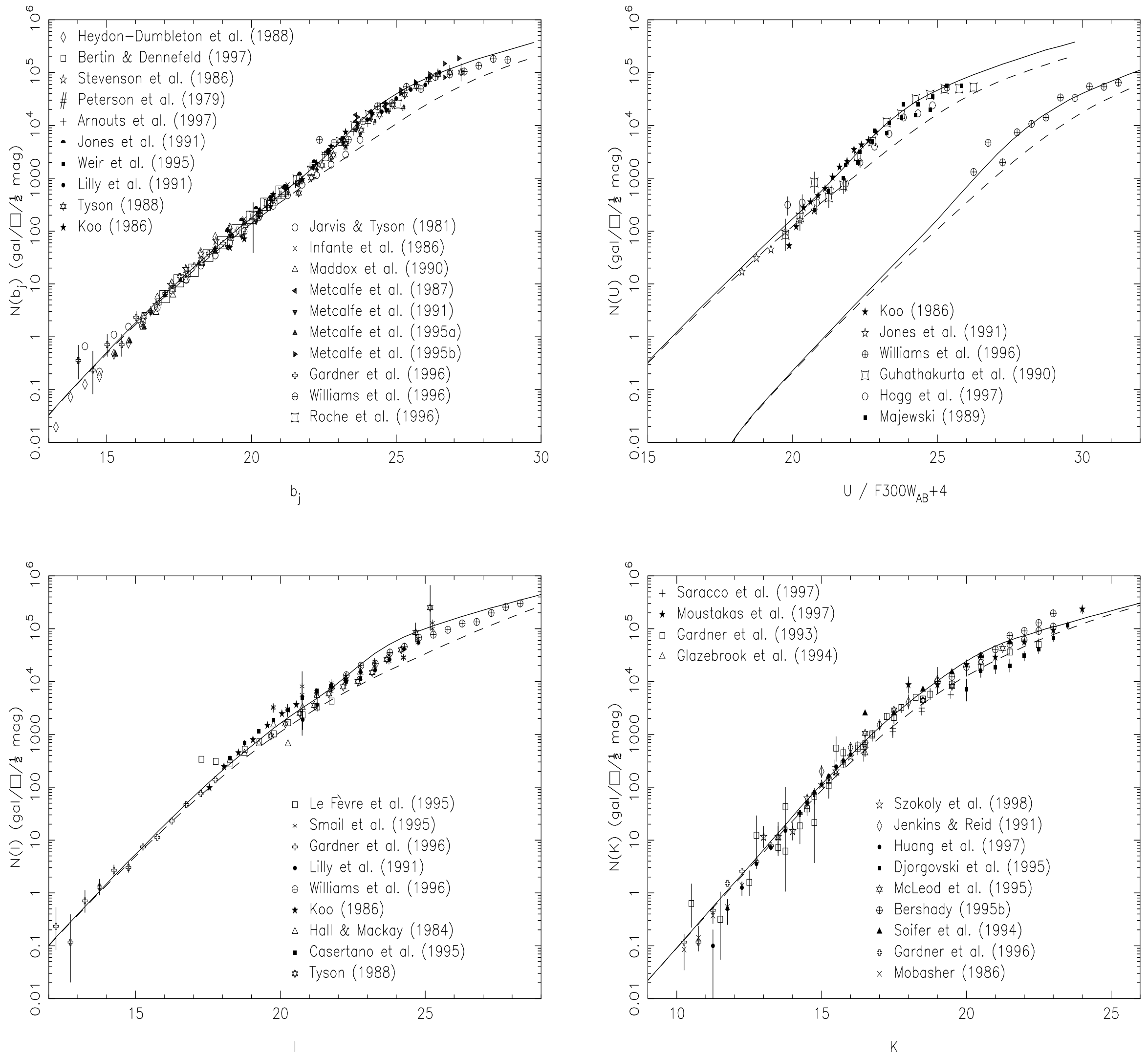

Figure 8: Predicted galaxy counts in b_J, U, F300W$_{AB}$, I and K compared to the observations and normalized to them at $b_J = 16$. The most constraining data are the Hubble Deep Field North data (Williams et al, 1996) The luminosity function is from (Heyl et al., 1996). The adopted cosmology corresponds is $H_0 = 65\,\mathrm{km.s^{-1}.Mpc^{-1}}$, $\Omega_0 = 0.3$ and $\Lambda_0 = 0.7$. The dashed line is the case without evolution (From Fioc & Rocca-Volmerange, 1999, A&A 344, 393).

companions of these active galaxies could explain the formation of proto-structures and by a merging effect, the formation of elliptical galaxies. The merging of sub-units embedded in relatively small dark halos towards the formation of massive elliptical galaxies at recent epochs is now a generic scenario quite compatible with the most recent simulations of galaxy formation. However the two HDF fields cover only 0.003 deg^2 down to $AB \simeq 28.5$ and the small value of the volume occupied by the HDF fields may be very sensitive to line-of-sight clustering variations, the so-called cosmic variance. Expanding the size of the observed field to angular scales typical of large scale structures is necessary to get a more balanced view, and reach structures on scales up to $\simeq 50h^{-1}$ Mpc for the first time at this depth. This is one of the main goals followed by the Deep survey of the CFHLS.

3.6.2 Galaxy evolution and star formation history

The expected sample of galaxies in the Deep survey will reach a level of about 10^6 galaxies, by a simple extrapolation of HDF counts (increase by a factor of 500 for any numbers), and some 10^4 QSO's should be identified. At the depth required by the survey, galaxies 5 to 10 times fainter than M* will be detected up to a redshift 3 to 4. With such a huge and homogeneous sample of galaxies, the luminosity function of galaxies will be built at each redshift and with small steps up to $z \sim 4$. Several thousands of "g'-dropouts" galaxies will be identified reducing the statistical noise in the luminosity function to levels quite comparable to local estimates. With the large amount of galaxies detected in the survey, a sample of Lyman-break galaxies can even be built at unprecedented depth and redshifts, possibly up to $z \sim 8$ if galaxies are already formed at that epoch (r' and i' dropouts).

The $u^\star$ band survey is exceptional to measure the activity of star formation at high redshifts. Due to the extremely blue slope of SEDs for star forming galaxies and starbursts, their detections will be favored at higher redshifts. The consequences on the estimate of a global star formation history are most constrainful.

Key observations will be to split this sample in redshift, luminosity, morphological type and local environment bins. The huge number of galaxies of the sample will reduce the statistical noise to its minimum and will allow accurate measurement of the critical outputs such as the luminosity function. Built in different environments (empty fields, groups and clusters of galaxies, or any overdensity of galaxies) the luminosity function will be the tracer of the relationship between galaxy formation mechanisms and the local overdensity of dark matter, especially at high redshift. Thanks to the depth of the survey, it will be extended to its faint-end where the behavior of intrinsically faint galaxies is still uncertain and not well understood. The extension at high redshift and faint magnitudes of the luminosity function is a powerful test to discriminate between scenarios of hierarchical galaxy evolution and monolithic formation.

Another aspect of the survey is the use of galaxy morphologies to compare the rate of stellar evolution in different galaxy structures. To do that, it is necessary to use some 2D image fitting and classification with possibly some deconvolution tools. Although the survey will never reach the resolution attained with the HST, we can expect that most of the Deep survey observations will be done with a seeing better than 0.7", at least in one or two colors. At least 3 major groups of morphological types will be separated: E, Sp and Irr, allowing a detailed analysis of the evolutionary processes for the different classes of galaxies. The present day understanding of galaxy morphological evolution is that spheroidal components formed quite early in the Universe and then evolved passively, with a slow increase of their mass by accretion of small units present in their environment. On the contrary, spiral disks and irregular galaxies, hosting more continuous stellar formation formed more recently and seemed to follow a more chaotic evolution where starbursts were changing the appearance of these objects. Anyhow this simple scheme is not fully accepted and large statistical samples of galaxies are required to disentangle local effects affecting some individuals and the more global scheme of galaxy evolution.

3.6.3 Quasar evolution, statistics

As already stated, the HDF contains essentially galaxies and very few stars and quasars. Looking for quasar candidates, Jarvis and Mac Alpine (1998 AJ 116, 2624) detected 9 point-like objects only with B-V>1.5, 12 quasar/AGN candidates with z>3.5. Cohen et al. (2000, ApJ 538, 29) found 11 spectroscopically confirmed stars and 2 broad-lined AGN only in their spectroscopic survey of HDF North. Statistical uncertainties are thus quite large to derive any conclusions on the statistical properties of quasars at very faint magnitudes. Anyhow, some methods are starting to emerge to select quasar candidates, based on successive fits to numerical templates of galaxies, quasars and stars, leading to a photometric redshift estimate and to a spectral classification. This method will soon be tested spectroscopically up to I = 24.5 thanks to the VIRMOS-DEEP redshift survey. Its extension to the CFHLS Deep survey should produce a sample of several thousands of quasars with a secure identification. Extending the number counts of such objects to very faint magnitudes is essential to understand the physical processes occurring in the central engine and their relation with the host galaxies in the general framework of galaxy evolution. In addition, unprecedented constraints may be expected on the quasar density at extremely faint magnitudes. The mapping of high redshift large scale structures can also be done from the QSO distribution, as well as the space correlation function of QSOs at these scales.

Related to the mapping of the deep Universe with QSOs is the still pending question of resolving the diffuse X-ray background. Although the new generation of X-ray satellites is close to solve that question, the optical identification of the faintest X-ray sources is crucial to better understand the physics of AGNs and the way the light is re-emitted from the central engine.

3.6.4 3-D distribution of galaxies and AGN environments

The clustering of high redshift galaxies is one of the clues for a better understanding of the hierarchical assembly of dark halos in the early Universe. Traced by the galaxy correlation function (2D and/or 3D), this fundamental issue is one of the clues of the general scheme of the formation of structures. It is a key to better understand how well galaxies trace the mass structures and to quantify the “bias factor”. The redshift dependence of the bias factor is also a tracer of galaxy evolution and a test of the scenarios of galaxy formation.

In practice, the use of photometric redshifts can partly raise the degeneracy induced in the 2D correlation functions of galaxies. Moreover, a strong influence of the Hubble-type of the galaxies is already known in these correlation functions, as for example early-type galaxies are more clustered than late-type ones, at least up to $z \simeq 1$. Extending this study at high redshift and using a morphological and/or spectrophotometric classification of the objects is another approach to test the models of galaxy evolution, more sensitive to the cosmological framework than number counts. It requires a sample of high redshift galaxies ($z > 2$) as large as several thousands, in order to separate the different galaxy-types and an area of several Megaparsecs at $z \simeq 2$, as the typical correlation length of galaxies is 8 h^{-1} Mpc or 0.5 degree at that redshift.

More specifically, the properties of galaxy companions, in the closed environment of quasars and radio galaxies, will be established with statistical tools (colors versus distance, correlation function, alignments with the radio jet in radio sources). Consequences on the role of the AGN activity on star formation process in halo structure are constraining models of galaxy formation.

3.6.5 High redshift clusters and proto-structure formation

Although the expected number of very high redshift clusters ($z > 2$) is rather low in the area covered by the Deep survey (a few units, if any), this number is extremely sensitive to the cosmological world model and is expected to be a strong test of the cosmological parameters. In addition, the dynamical and morphological status of such structures may be quite different to structures known in the local Universe and their aging can give some clues on the time-scales in progress during the growth of structures.

3.6.6 Data requirements

These ultra-deep observations will be made on the four fields monitored by the SNe factory program which will provide data with enough depth on all of the SDSS filters but u*. The same exposure time with u* as with g' is deemed to be enough. The amount of observing time required in addition to the SNe observations is 33 hrs per field, for a total of 20 QSO nights. Conditions with average seeing better than FWHM=0.7 arc-seconds should be used to build this dataset. This will allow 2D image fitting to identify broad galaxy types. Though u* is not required by the SNe component of the CFHLS, this filter provides, for the supernovae at low redshift (say $z < 0.3$), a complement to the g' filter at higher redshift, improving our ability to type and k-correct the supernovae within what will quickly be the single largest and only photometrically uniform survey ever done.

3.6.7 A note on photometric redshifts

A multi-color dataset is required to get photometric redshifts for galaxies and quasars. The expected accuracy on these redshifts with the proposed survey is presented elsewhere (Pelló et al. 2001), and is about $\sigma_z \sim 0.1(1+z)$ or even better at high redshift. The main change compared to samples of galaxies with spectroscopic redshifts is that the photometric redshift technique gives a probability function in the redshift space, which requires a refined statistical approach to deal with the uncertainties in the redshift estimate. In addition, spectroscopic sub-samples are recommended to calibrate and check the photometric redshifts, but photometric ones are of prime importance beyond the spectroscopic limit. With the characteristics of the CFHLS deep survey, simulations have shown that photometric redshift estimates will be available for more than 2/3 of the galaxies, especially in the redshift ranges $z < 1.2$ or $z > 2.2$. Note also that $u^\star$ information is crucial for the determination of photometric redshift, especially when near-IR data are not present.

Anyhow, without near-IR data, errors are relatively high in the range $1.2 < z < 2.2$ where about 30% of the galaxies may fall. A reasonably deep near-IR survey, possibly with WIRCAM, will reduce the uncertainty to $\sigma_z \sim 0.2$ everywhere. However, at $z > 2.5$ the expected contamination due to catastrophic identifications in the $1.2 < z < 2.2$ range is negligible (less than a few %) and is only slightly appreciable at $z < 0.5$ (about 10% of the total population). Deep near-IR observations are quite complementary to this survey and will reduce the redshift uncertainties to a homogeneous level, whatever the redshift. This may represent one of the priorities of what could be the "Wircam legacy survey". Multi-wavelength follow-ups can be foreseen and may infer the choice of the selected fields: XMM-Newton deep fields, SIRTF ...

4 Scheduling of the CFHLS observations

4.1 What is left to other programs?

There are presently 200 nights a year labeled as "dark" (16 nights per lunar month). The WG proposes to consider the use of MegaPrime on dark/gray time defined as the 18 night period centered on the New Moon. i' and z' observations can still be done reasonably well 9 days from New Moon. Using this definition, there are 225 dark/gray nights which are shared with Korea and Taiwan (17 nights total) and Discretionary Time (D Time, 12 nights). With the D Time considered a separate community (D) entitled to 12 nights, we are left with 208 nights a year to be offered to the C, D, F and H communities. The WG proposes a uniform distribution of the survey time over the five years of its duration, i.e. 525/5 = 105 nights. The CFHLS won't use poor seeing nights, estimated to represent 15% of the clear nights. Of the 177 available nights, the survey will require ∼59%. The fraction of "good" nights (seeing of 0.9" or better) left to other programs is ∼41% for each community, a reasonable fraction considering the large number of astronomers potentially served by the CFHLS. These ∼ 80 good seeing nights open to the communities will allow original programs to be carried out, including medium size surveys, at the discretion of the Time Allocation Committees. They will also give the opportunity to complement the CFHLS for specific purposes, adding to the CFHLS initial value. If UH is not participating, the load of the CFHLS on the Canadian and French communities increases to ∼69%, leaving ∼31% available to PI oriented programs. Figure 9 shows the fraction of observing time *with good seeing* left for allocation to other programs as a function of the CFHLS size.

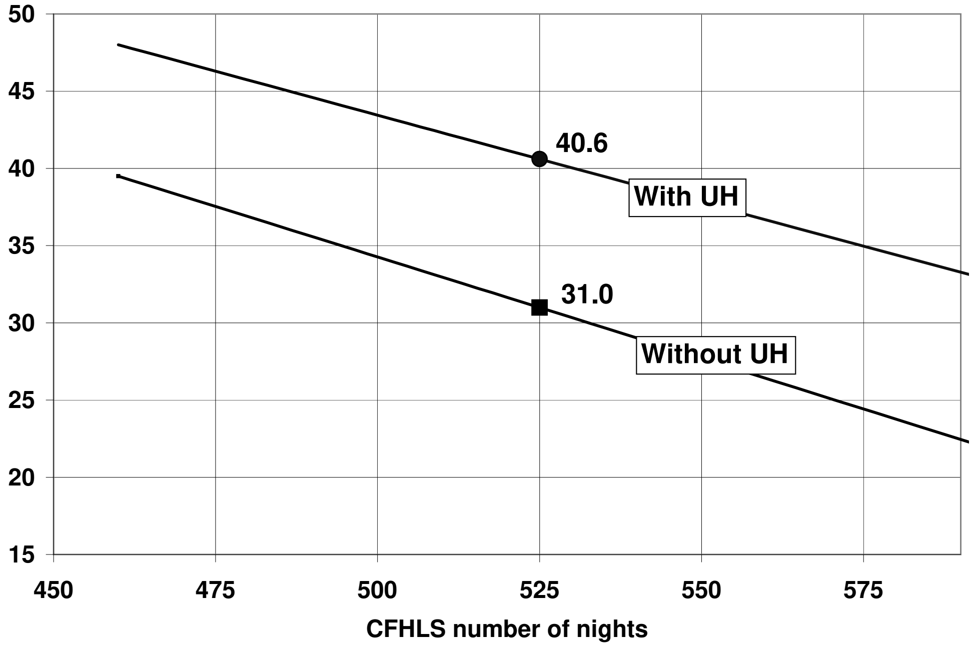

Figure 9: The percentage of observing time *with seeing 0.9" or better* left to the participating agencies for other programs

4.2 CFHLS fields and telescope scheduling

The SNe Factory component of the CFHLS requires an uninterrupted series of dark runs over four to five months on each of the four 1x1 degree fields. If we devote an entire dark run to other instruments, we interrupt the series and this has to happen when we switch from one field to another one. If it happens twice a year and if we don't want to interrupt any series of observations, it means that the fields have to be observable by pairs over 5 runs in a row. As a consequence, the choice of the pairs of fields dictates when the other instruments can be scheduled, bringing a strong limitation to the programs they can perform.

Instead of planning for complete dark runs without MegaPrime, we propose to schedule the other instruments requiring dark time over half a dark/gray run, i.e. 8 or 9 nights, and to mount MegaPrime for the other half. By doing so, we would never completely interrupt any ongoing series of observations on the SNe fields. The fields selected don't need to be chosen by pair of close Right Ascension (RA) and the transition from one field to another one along the year is done smoothly, with most of the time two fields observed in parallel. Such scheduling has in fact been implemented with CFH12K and MOS in October 2001. The MOS/OSIS allocated time is going to decrease in the coming years with the arrival of more powerful instruments on Gemini and the VLT, and OASIS won't be available on the telescope anymore in 2003. MegaPrime is likely to be mounted for 16 to 18 nights a month for most of the months, with only a few runs (2 to 3 a year) split between MegaPrime and another instrument.

With this approach, it makes sense to spread the wide synoptic and deep synoptic components as much as possible in RA. The fields proposed, in two groups at [22,2] and [10,14], are a good choice, though other fields could be chosen. At this point, the XMM field is a to-do for 10×10 square degrees. The Groth Strip at (10,+52) is also very appealing. The two other fields are tentatively placed at (22,0)(SA22) and (10,0). SA22 is not a very good choice as the extinction is substantial, but alternatives exist within 1hr in RA and 15 degrees in declination. A field at (10,+44) has been proposed, which will be observed by the Large Zenithal Telescope. It is another Northern field, not likely to be observed by other surveys in other wavelengths and not accessible from ESO. The field selection is tied to the participating agencies (UH or not UH) as well as to the final number of nights allocated. This selection will be made with SAC after a last consultation of the communities.

5 CFHLS administration

There are various ways to organize a project like the CFHLS. The following scheme is proposed to SAC as one model which is likely to work, with a Steering Group representing the various institutes participating in the CFHLS, and individuals who will actually make the CFHLS happening.

5.1 Steering Group

A CFHLS Steering Group (SG) will oversee the execution of the CFHLS. It will report to SAC and through it to the CFHT Board. A suggested membership should include a representative of each of the participating agencies (they give the observing time to the CFHLS), and of CFHT, CADC and TERAPIX where the CFHLS will be executed from the data collection to the CFHLS final release. The coordinators (see below) will also be members of the SG. Both operation and science should be well represented, and the membership should be balanced between the participating communities. Other members could be added as SAC sees fit to appoint.

The SG should be formed as soon as a decision on the CFHLS has been taken, and the MSWG should disappear. The first task of the SG will be to prepare a charter for its duties and responsibilities, to define the final characteristics of the survey in collaboration with SAC, and to organize the administration of the CFHLS as overviewed in this document. Among other things, the SG will encourage the collaborations within the communities, centralize the information on the collaborations organized with partners outside the participating communities, and coordinate the CFHLS real time activities in close consultation with CFHT.

The progresses of the CFHLS, once started, should be reviewed once a year by external referees under SAC responsibility. This review process will give to the communities, through SAC, the possibility to modify some of the CFHLS goals, or to change the CFHLS design or strategy, if required by the emergence of new important fields or the poor results coming from the CFHLS itself.

5.2 Coordinators and Monitoring Groups

Each of three components of the survey, the data processing and the data distribution will each have a Coordinator, whose role will be to insure that the goals of the survey are met through a regular evaluation of the CFHLS products and through a continuous interaction with the involved communities and the SG. As the task is immense, the Coordinators will each create a monitoring group (MG) as open as possible to any community member keen to participate. Being a member of a MG gives to anyone concerned by one of the CFHLS components the possibility to participate into the data acquisition and evaluation at various steps in the CFHLS data flow. The membership from the different communities will help to ensure that active collaborations are maintained.

The Coordinators will be able to delegate some of their responsibilities, if needed, to other members of their monitoring group, keeping the SG and CFHT aware of who is in charge when. The operational aspects of the CFHLS are indeed very important and require a clear identification of who has authority at any time on each of the three survey components. Thanks to the CFHLS clear proprietary policies, the Coordinators will not have any privilege with respect to data access, and should not be seen by the communities as the owner of the component they are in charge of. The Coordinators could be appointed by the SG, or proposed by the SG to SAC, which would then appoint them. The Coordinators will be members of the SG. Some of them could already be member as one of the representatives mentioned earlier.

5.3 Science Groups?

To have scientific groups created around the various scientific goals of the CFHLS is another step the WG has examined. The MGs will gather individuals sharing similar scientific interests and will give them the opportunity to share also their ideas and projects if they wish to do so. Should these informal groups be made more official is an open question. Many in our communities do not see "science by committees" as a good thing... The MGs will however provide a framework in which more focused science groups could start from the initiative of those willing to formalize their collaborations.

5.4 CFHLS execution and community awareness

It is expected that CFHT will take responsibility for executing the observations in a QSO mode similar to the mode used now for CFH12K. Through daily and monthly reports, CFHT will keep the communities informed of the progresses made in the CFHLS data collection as it does for other QSO programs. It is also expected that the five Coordinators will report on a monthly basis on their activities in a very open way, giving an essential feedback on the quality of the data and the overall CFHLS progresses to the communities.

6 Policies for data access

The WG recognizes the need for establishing a proprietary period during which the products of the survey program will not be freely available to the worldwide astronomical community. The purpose of a proprietary period is to protect the investment of the resources of the participating communities. A proprietary period is meant to ensure that community members are given the opportunity to get a "head start" on scientific analysis thus giving them an advantage over astronomers outside of the member communities.

A definition of which persons are allowed access to the data from the survey program is required. For both practical reasons and considerations of principles, the WG recommends that access to the survey data be controlled by establishing a list of individuals. Individuals will apply to the Director of CFHT stating the reasons that they should be considered "survey program members" and the Director would approve or reject these applications.

Survey Program Members will include:

- Astronomers, Post-Doctoral researchers, graduate students and others employed by, or enrolled at universities and institutes in the participating communities.
- Astronomers and others who have contributed to the survey planning, development and execution or have contributed to plans for the scientific analysis. This includes

astronomers and others who may have worked in one of the participating communities and have later moved to institutions outside of them.

6.1 Proprietary Policy for Survey Program Members

All survey program members will have equal access to the data for the purposes of scientific exploitation. No group or individual will have the advantage of period privileged access which allows scientific exploitation. Because the facilities where the data are processed will have possession of the data for some period of time, those data must be released to survey members immediately upon completion of processing and before any scientific analysis is begun by any groups associated with the processing or any other groups. Although there may be several channels for distribution of data there will be no "privileged" channel, which would allow one group of survey members or individual survey members to begin scientific exploitation earlier than is possible for the general community of survey program members.

Un-processed data (that is data that is either raw or has had basic pre-processing i.e., removal of instrumental signatures) will be released to survey members immediately, subject only to practical considerations. The goal should be distribution within 30 days of completion of the observations and it is expected that this goal will be realized within 3 months of the beginning of the survey program. This distribution path is meant to provide any survey member with the ability to obtain the data as soon as it is produced even though the data quality may not be optimum. This distribution path should include data which CFHT has processed in "near real-time".

Fully-processed data will be released to the community of survey program members as soon as processing is complete. The goal should be distribution within 60 days of the completion of all of the observations that are necessary components for the production of fully-processed data.

Data "releases" as outlined below may also be made to the community of survey program members where a release is defined as a logically complete and homogeneous datasets that is a subset of the entire survey program. These releases are likely to contain the best data for scientific exploitation. Data releases may contain data that are processed in a different and superior manner and so may differ from those data released immediately after they are fully processed. Nevertheless, data will not be withheld from survey program members in anticipation of a data release. As soon as the data are initially deemed "fully processed" then they will be released. The WG recognizes that there is a danger of confusion among data products processed and released at different times as a result of the policy defined here. The WG balanced this potential problem against the problem of having a data release program that might be perceived as not being fully open. The latter problem is more serious.

Fully-processed data is defined as data that, in addition to the removal of instrumental signatures, has been geometrically corrected, astrometrically calibrated, photometrically calibrated, and co-added, perhaps with PSF homogenized.

6.2 Proprietary period for the general astronomical community

The WG recommends that the release of data with the instrumental signatures removed (which will be produced at CFHT) be in accordance with current CFHT policy. Specifically, data should be released to the general astronomical community approximately one year after the observations are obtained. The WG recommends that the proprietary period be modified to one year after initial processing at CFHT is completed. The Director of CFHT should have the power to modify that data release schedule if application is made and persuasive arguments are given.

The distribution of fully-processed data to the general community will be via data "releases" at specified times during the course of the survey program. The WG recommends that the first data release take place 3 years after initiation of the observational program. The final release will be one year after the completion of observations for the survey program.

The intent of data "releases" is to distribute a homogeneous and well-calibrated dataset that can be used for multiple scientific purposes. It is anticipated that it may take as much as 3 years to produce a sizable dataset that meets these criteria. A data release would not be expected to contain all data produced up to a particular date (e.g., 1 year before the data release) but should consist of a logically complete and homogeneous dataset.

6.3 Collaborations outside the CFHLS communities

The WG recognizes that it is in the interests of CFHT and the communities to have the CFHLS data used very widely and to encourage the maximum scientific productivity from those data through collaborations which often would extend outside the participating communities. Though such collaborations raise a legitimate fear of CFHLS proprietary images unreasonable dissemination, the WG does not think that regulating these collaborations is both appropriate and realistic. However, the WG recommends that astronomers intending to form such collaborations where significant amounts of CFHLS data are going to be shared with astronomers outside of the CFHLS community should inform the Steering Group and the director of CFHT of this collaboration so that SAC and CFHT Board can be kept informed and eventually decide whether a problem exists that needs to be addressed by the development of policy.

6.4 Real time data products

At least two real time projects are for now well identified: the search for SNe and the search for moving objects. The WG proposes the following policy for the publication of the detections:

- As soon as validated, SNe and moving object position/photometry are made available to the community through the appropriate channels (IAUC, Minor Planet Center, ...) which releases them. The main driver for this policy is that we can't insure that we will be able to follow the object up. CFHT can get weathered out or be at the end of a queue run, and it would be a pity to lose the object because it is kept for our eyes only.

- As the pipelines are requiring work and skills from many people, the announcements would be made the same way it is done now for SNE or moving objects discovered by dedicated programs. It would be labeled a CFHLS product with the names of the individuals who will have contributed to the pipeline(s) and validation.

This is standard policy for the projects devoted to large discovery programs in both the SNe and solar system communities. In case of a discovery of such a nature that it should be kept confidential for some time, a case should be made to the CFHT Director who could then override the common rule.

7 Data Processing

The provision of adequate capabilities for processing of the observations for the survey program into usable data products is fundamentally important for the success of the project. This is because the large data volumes produced by the survey program will be difficult for many individual research groups to process and store with their own resources. It would therefore be difficult for the communities to scientifically exploit the survey output in the absence of a good processing capability.

There are three major classes of processing that are required. The first is the basic preprocessing or removal of instrumental signatures. The second is the more sophisticated processing needed to produce final data products that are geometrically-corrected, co-added and calibrated (photometrically and astrometrically) and where homogenization of the point-spread function (PSF) may have been done. The third class of processing is "near real-time" processing that may have unique requirements and features to satisfy specific science objectives.

The first class of processing would be undertaken at CFHT under the current proposal. The second class of processing would be carried out at processing centers of all partner communities with the strong involvement of the TERAPIX group. The third class of processing needs to be done quickly and so CFHT is the probable location.

The WG has received a report from TERAPIX and commitments from CFHT and CADC to do certain things. The recommendations in this report have been reviewed by those organizations and firm commitments have been made both in France (TERAPIX) and Canada (HIA/CADC) to secure the funding allowing the various tasks outlined below to be performed for the duration of the CFHLS execution for a data yield corresponding to the three components of the CFHLS as proposed in this report.

Finally, it should be noted that each of the communities needs to feel that they have had adequate input into decisions about exactly how the processing is done. During the next months it is important to have the plans for data processing reviewed by all partners and suggestions for changes be adopted and finally for the partners to approve a processing plan. TERAPIX needs to lead this process.

7.1 Pre-processing or removal of instrumental signatures

CFHT has committed to operating a processing environment which will quickly produce MegaPrime images with the instrumental signatures removed (i.e., bias-subtracted, dark-subtracted, flat-fielded, and fringe-corrected). This processing is being done for CFH12K in close collaboration with the TERAPIX group so that the methods used at CFHT will be consistent with those used by TERAPIX and the CFHT processing should provide data that represents the first stage of processing by TERAPIX and the further TERAPIX processing will be consistent with the CFHT procedures. It is important that this be the case. It is important to avoid multiple data products that have followed different processing paths and the confusion regarding data integrity that would follow. Close collaboration between TERAPIX and CFHT needs to be maintained.

7.2 Processing of final data products

The French community and funding agencies showed great foresight in providing for the development of a leading-edge processing facility for MegaPrime data. Without such foresight the effective scientific exploitation of the survey program would be in doubt. The TERAPIX group has been working for several years developing software and systems for MegaPrime data processing and has completed most of the components for CFH12K processing. It appears very likely that TERAPIX will have software ready in time for use in processing the output of the survey program.

TERAPIX has agreed to make freely available to the survey program communities the software and expertise that has been developed and that will be developed for the MegaPrime survey program. The documentation and source code will be freely available so that algorithms and implementation details will be clearly understood by users of the TERAPIX software.

TERAPIX has agreed that the most effective operational model is one where data processing is shared among the participating communities rather than centralized at one location. The WG agrees that this is the most open and cooperative model and that it should be adopted. This model would place processing burdens upon each of the partners and associated costs of building systems for carrying out the task. All three communities must evaluate these requirements and commit to carrying out their share of the processing tasks.

The WG recommends that the French center for processing of MegaPrime final data products be the responsibility of the TERAPIX group. It recommends that the Canadian processing center be the responsibility of the Canadian Astronomy Data Center, which has received the necessary support from HIA for carrying this task. Would Hawaii participate, the Hawaiian center would have to be defined.

There is no reason to prevent processing from being done at other sites by other research groups. However, only specified groups should be allowed to distribute data to the wider community so that adequate control of data distribution can be maintained under the authority of CFHT.

7.3 Near real-time processing

In some cases, very rapid data processing is necessary. CFHT has been proposed as the site to provide an extension to the CFHT processing environment so that particular data could be flagged and processed through additional steps according to recipes (and software) provided by the scientific users. The users would provide modules conforming to standards defined by CFHT and these modules would be "plugged in" to the processing pipeline. The user will need to visit CFHT to oversee installation and testing of their processing modules in the CFHT environment. This will certainly place additional support burdens upon CFHT.

The WG believes that this ambitious proposal from CFHT is a good one and fully supports it. In any case, the processing needs to be done near in time (and perhaps in space) to the observations so that CFHT is the logical place to locate a "near real-time" processing capability. At least two well-identified projects based on rapid detections, SNe and solar system moving objects, should implement pipelines at CFHT. Another one on variabilities and transient phenomena is also envisioned. At least at the beginning of the CFHLS, and possibly for its all duration, it is anticipated to have more than one processing pipeline per project working with different algorithms and implementations, in order to get a more robust system and to secure the detections.

The CFHLS Steering Group will coordinate these real time activities in close collaboration with CFHT in order to avoid any unnecessary duplication of efforts.

8 Internal Data Distribution and Data Access: CFHT, CADC, TERAPIX and CDS

The Working Group now envisions a dataflow model where all CFHLS (and presumably other MegaCam) data flows from CFHT to CADC. At CADC the data will undergo some preliminary verification (headers intact, all pixels received, metadata received and consistent) and the book-keeping associated with the dataflow would be initiated. At this point the raw (or ELIXIR-processed) data would be catalogued, ingested, and be made available to community members as quickly as possible. The data would then be transferred to TERAPIX -F (French TERAPIX) and TERAPIX-C (Canadian TERAPIX) locations for processing.

When processing is complete to the stage where an archive-able product has been produced, this product would be returned to the archiving system and be verified, ingested, catalogued, and made available to the survey community. The "book-keeping" database would be updated to reflect the current status of the flow of data and processed data. At any given time, the "book-keeping" database would contain the location and status of all data produced by CFHT that has been received at CADC.

The *Centre de Données de Strasbourg* (CDS) will offer to the participating communities the possibility to access these processed images through its tools, using the images stored online at CADC. CADC will take care of regulating the access to the survey members only, as these processed data are not in any way going to be public but through the CFHLS data releases as outlined earlier.

Numerous technical details need to be defined before a practical plan can be agreed upon for transporting data between CFHT, CADC, and TERAPIX. How will the data move from CFHT to CADC? From CADC to TERAPIX and back? These very important issues are already being discussed between the involved institutes and will be given the highest priority as soon as the CFHLS proposal is accepted.

9 Data Distribution to Scientific Users

The issues that need to be addressed by the data distribution plan are:

1. Access to data needs to be easy, quick, and without obstruction to survey program members

2. Data access needs to be controlled by CFHT

The data flow from observatory to processing centers and to the scientific users will consist of some combination of tape, optical media, and network. The job of convincing the communities to support the CFHT survey program requires that the communities will have quick and unhindered access to whatever data products they need in order to do the science that they want to do. A competing requirement is that access to data be controlled during the proprietary period.

Each of the communities needs to feel that they have had an adequate opportunity for input into the plans for data processing. Although some dialogue has occurred between TERAPIX and CADC concerning processing of MegaPrime data, the dialogue has been limited and Hawaii has not been included. This process needs to take place and be lead, presumably, by TERAPIX.

The MegaPrime Science Working Group has discussed data distribution in the context of existing facilities. In Canada the CADC has distributed CFHT data for a number of years and the working group notes that this will continue with CADC being the primary data archive and distribution center for Canada and that the CADC service will be available to all of the communities, as it is at the present time.

The most cost-effective approach to data archiving and distribution is to utilize existing facilities and so the Working Group is pleased to note that CADC will be the primary data archiving and distribution center for MegaPrime data.

A sketch of the CFHLS Data Flow is outlined in Figure 10.

9.1 Distribution of pre-processed data

The WG consensus is that all data that have been pre-processed at CFHT should be archived at CADC in the usual way, stored online, and distributed to all survey members from this facility. In addition, raw data should be archived at CADC. The CADC would have primary responsibility for data security and preservation of raw data.

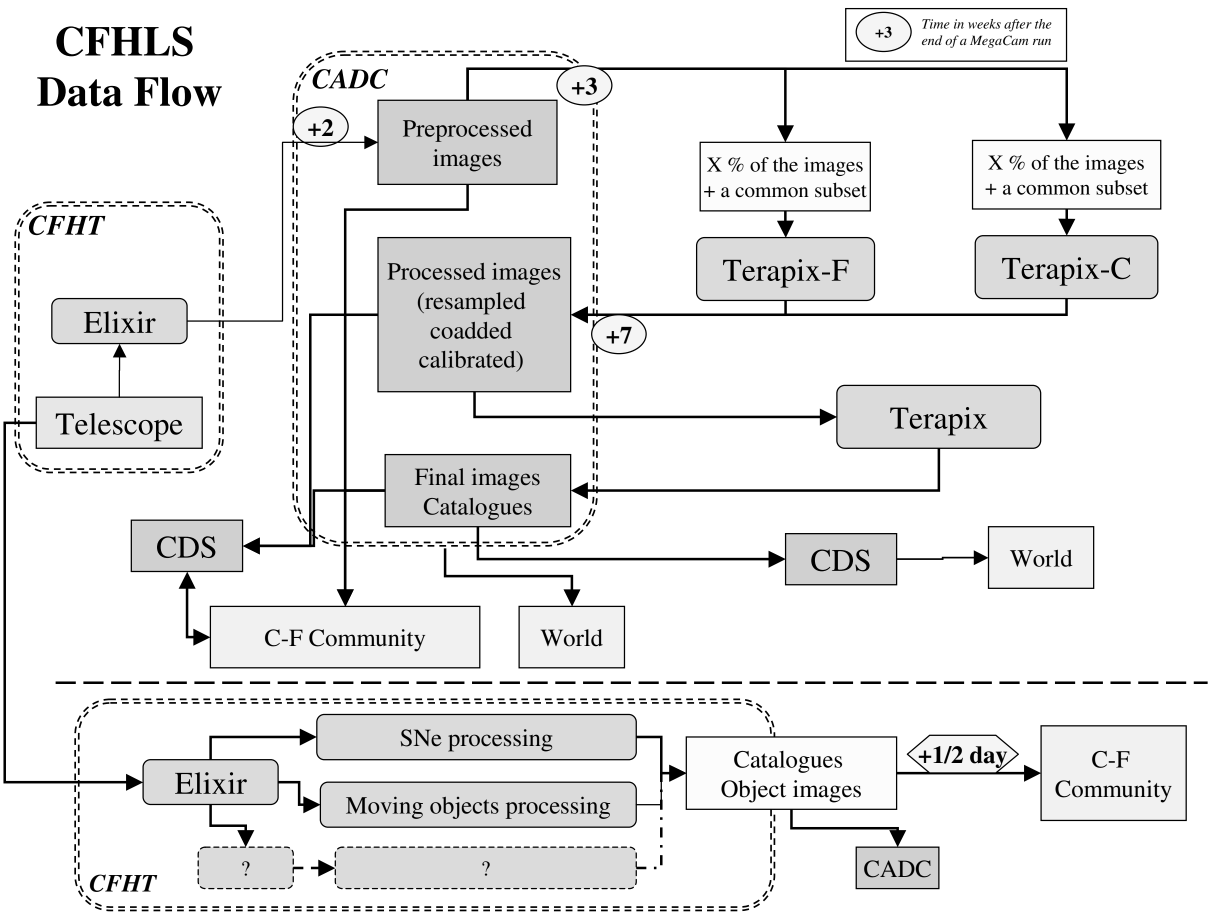

Figure 10: An outline of the proposed CFHLS data flow

9.2 Distribution of fully-processed data

As outlined above, the recommended data processing model would have each of the participating communities processing a subset of the data with significant overlaps for the purposes of verification of the correct functioning of the pipelines. Thus, data would travel from CADC to each of the processing centers, would be processed and the results would need to be reassembled into a complete archive for distribution. The WG has agreed that CADC will be a site (perhaps not the only site) where this occurs. The fully processed data would then be distributed to survey members and, eventually, to the wider general community.

CDS will also provide an indirect access to these data with the added value of services like VizieR or Aladin (http://cdsweb.u-strasbg.fr/).

Though there are many details to be worked out, as already mentioned earlier in this report, the consensus within the WG is that the number of distributing sites be limited to at most one in each of the partners region. To have actually only one such center (CADC) would enormously simplify the communications to take place between these various sites to ensure proper coordination of data distribution. This is the solution the WG proposes.

9.3 Distribution of "near real-time" processed data

There is a strong motivation for some science areas to have data distributed as quickly as possible. In this case, we recommend that CFHT have a quick access channel directly from CFHT to the science users. These channels would need to be created by special arrangement considerably in advance of the observations and would need to be coordinated with any "near real-time" processing that is required.

If CFHT distributes "near real-time" data directly to science users, then it must simultaneously distribute the same data to CADC for general distribution to conform to the principle that there be no period of "privileged access" for scientific exploitation by any individual or group.

9.4 Distribution of data releases

The WG envisions a first data release to the world three years after the beginning of the CFHLS execution. It could be made of first 6x6 square degrees patch in two colors, or a first significant continuous area of the very wide field. The data release would then continue by steps (on a yearly basis) with, as an ultimate goal, a complete data release one year after the end of the proprietary period of the last CFHLS observations.

To determine now exactly what would be released after three years is difficult as the exact strategy of the CFHLS is not determined yet. Such a strategy can only be developed when the number of nights allocated to the CFHLS is well defined. It will be one of the Steering Group tasks, early in the survey, to define the CFHLS data release process.

9.5 Distribution of catalogues, previews, and other data products

CDS is likely to play a very important role in the catalog and preview distribution, thanks to the long experience acquired in this domain. CADC will obviously be associated to this distribution.

10 Acronyms

2MASS	Two Micron All Sky Survey
AGN	Active Galaxy Nuclei
AU	Astronomical Unit
BD	Brown Dwarf
CADC	Canadian Astronomy Data Center
CDS	Centre de Données de Strasbourg
CFH12K	Canada France Hawaii 12k camera (a CFHT instrument)
CFHLS	Canada France Hawaii Legacy Survey
CFHT	Canada France Hawaii Telescope
CITA	Canadian Institute for Theoretical Astrophysics
CMB	Cosmic Microwave Background
DEEP	Deep Extragalactic Evolutionary Probe (Keck/HST program)
DENIS	DEep Near Infrared Survey of the Southern Sky
DESCART	Dark matter from Ellipticity Sources CARTography
FWHM	Full Width Half Maximum
HDF	Hubble Deep Field
HIA	Herzberg Institute of Astrophysics (Victoria, Canada)
IAP	Institut d'Astrophysique de Paris
IAUC	International Astronomical Union Circular
IMF	Initial Mass Function
IfA	Institute for Astronomy (University of Hawaii)
MAP	Microwave Anisotropy Probe
MG	Monitoring Group
MOND	MOdified Newtonian Dynamics
MOS	Multi-Object Spectrograph (a CFHT instrument)
MSWG	MegaCam Survey Working Group
OSIS	Optionally Stabilized Imager and Spectrometer (a CFHT instrument)
PI	Principal Investigator
PSF	Point Spread Function
QSO	Queued Service Observing... or Quasi Stellar Object (look at the context!)
RA	Right Ascension
RCS	Red-sequence Cluster Survey
SAC	Science Advisory Council
SDSS	Sloan Digital Sky Survey
SG	Steering Group
SIRTF	Space InfraRed Telescope Facility (launch in July 2002)
SNAP	SuperNova / Acceleration Probe (a project)
TAC	Time Allocation Committee
TERAPIX	Traitement Elementaire, Analyse et Reduction des PIXels de MegaCam
TNO	Trans Neptunian Object (also called KBO for Kuiper Belt Object)
UH	University of Hawaii

VIRMOS	Visible and InfraRed Multi-Object Spectrographs (Two VLT instruments)
VISTA	Visible and Infrared Survey Telescope for Astronomy (a UK project)
VLT	Very Large Telescope (European Southern Observatory)
WD	White Dwarf
WG	Working Group
WIRCAM	Wide field InfraRed CAMera (a CFHT program)
XMM	High Throughput X-ray Spectroscopy Multi-Mirror Mission
XMM LSS	XMM Large Scale Structure survey

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