1 Ultra-deep Synoptic Survey Time Request

The total time request, for both the supernovae and the ultra-deep is for 270 queue nights, with $<$ 85% seeing (currently better than $1''$). Comment on the ultra-deep component is needed.

1.1 Overview

Supernovae measure the distance-redshift relation, one of the classical cosmological tests. This relation is strongly dependent on the the "decceleration parameter", q_0, now known to be a cosmic acceleration. The implication of the acceleration result is that some unknown field, the "dark energy" overwhelms even the well accepted "dark matter" for its influence on the overall dynamics of the universe. The tremendous opportunity is that the nature of the dark energy, in particular its equation of state, $w = p_X/\rho_X$, can be explored through its impact on the distance-redshift relation.

The proposed data will have an unprecedented level of precision. The median distance modulus for Ia supernovae below $z \simeq 1$ (depending on brightness) will be about 0.08 mag, such that each will give approximately a 2σ measure of the deviation of a $w = -0.8$ cosmology relative to a classical, fixed Λ cosmology with $w = -1$. Of course, the overall measurement precision depends on having data at many redshifts. The advance in precision is intrinsic to the CFHLS plan. We are "always monitoring" and the data should have outstanding photometric uniformity. This feature is important to give confidence that we reliably go into the regime of measuring the equation of state of the universe with good control over systematics.

The time request is based on extensive simulations to derive the expected precision of the survey, fitting the g', r', i' and z' light curves to various templates with four free parameters:
- time of peak brightness,
- peak brightness,
- "stretch factor", and
- dust extinction. Variants are considered at the end of this paper.

The observational quantities varied are image quality requirement (we assume we get the full distribution of image quality better than the stated value), the sampling rate, and the exposures in each filter. We generally assume that we can only get a given field 14-15 days a month. The ideal approach of having nothing other than image quality better than median seeing would use virtually all of the high quality dark time.

The statistical method used to recover the distances is the multi-light curve shape (MLCS) approach. To make this observationally feasible we devise an approach which uses the very efficient i' filter to do most of the work in following the light curve and the other filters have sufficient S/N to estimate the dust. The g' filter probes the UV at higher redshift (and is hence likely to be quite metallicity and population sensitive and not useful for dust).

1.2 Observational Details

There are two criteria used to set exposures to measure w to a precision of better than 5%. This requires control over random and potential systematic errors. The random errors are simply a matter of statistical errors in fitting templates to the light curves. The systematic errors require accurate color measurement around the time of peak light. The following observations will give $S/N > 5$ detections in $>$ 50% of all Ia at $z < 1$ in the r', i', and z' filters:
- g': 900 sec (important for $z < 0.5$ Ia)
- r': 1800 sec (crucial for extinction measurement)

- i': 3600 sec (light curve shape measurement)
- z': 1800 sec (crucial for extinction measurement)

To obtain the necessary time sampling the following is an acceptable algorithm for CFHLS supernova observations. OBSERVE:

- WHEN clear (∼75% of nights)
- AND moon down (possibly can be relaxed if fringing easily controlled)
- AND air-mass < 1.5,
- IF first or last night of dark run seeing $< 1.2''$ (<95% IQ)
- ELSE IF seeing $< 1''$ (85% IQ) (this includes all seeing better than stated limits) AND every odd (or even) night

The cost of this is 2.25 hours per epoch, with 6 epochs of 85% probability seeing and 2 at 95% probability seeing, for a "Megaprime blocks" of 5 months. Four fields are required for RA flexibility and providing a suitable range of 8m spectroscopy targets. The estimated rate is 18 (27) per month to redshift 1.2 (1.5). The higher redshift ones will be near our detection limits and may be "retroscpective" detections using the entire time sequence. Over 5 years this will yield the discovery of about 2000 Ia (with varying noise) at a cost of 2.25hours$(6 \times 0.85 + 2 * 0.95) \times$ 5months $\times$ 4fields $\times$ 5years = 1575hours. This is equivalent to 242 queue nights of 6.5 hours. To bring the u^* filter to the same exposure depth as g' in four fields (43.75 hours) will add an additional 26.9 nights. Consequently this minimal ultra deep synoptic survey will cost 270 queue nights. This represents 35% of the better than $1''$ (85% IQ) time.

The requirement for no moon results from the concern that MegaPrime fringing will limit and possibly bias our photometric accuracy. That is, fringing alone requires a frame to frame correction. Having a variable uniform background as well gets one the regime of having two variables and only one measured quantity.

If the weak lensing finds that 85% IQ time is also acceptable these components of the survey will use 61% of the better than 85% IQ time, nominally $1''$ with the CFH12k, and perhaps $0.9''$ with Megaprime. Jointly the two approaches will measure Ω_M and Ω_Λ to about 1% and w to about 3% precision.

2 Synoptic Strategy

An optimal observing strategy for supernovae will minimize the random and systematic errors in estimating distance for a fixed amount of observing time. To design the supernovae photometry we use Tonry's "Monte" supernova simulator and his Mauna Kea observing condition simulator. These simulators are based on real world data:

- six low redshift Ia, 91T, 90N, 98aq, 94D, 92A and 99by
- k-corrected SDSS magnitudes are available from z=0 to 1.8 based on current knowledge of spectra and k-corrections. There is a substantial element of extrapolation in some parts of luminosity function and redshift, but this is the best available material.
- peak magnitudes are calculated from the current knowledge of the Ia luminosity function,
- a realistic dust extinction is included,
- observing conditions include seeing, atmospheric extinction and fraction of night clear.

The estimated limiting magnitudes for 1800 sec integrations come from three sources:

- BRIZ data from the CFH12k scaled to Megaprime
- throughput calculations using CFHT and Megaprime QE's
- R and z′ data from the CFH12k

g'	r'	i'	z'
26.3	25.6	24.9	23.5

1800 sec limiting magnitudes (Vega system)

A set of SDSS band light curves for a Ia B_{max} are shown in Figure 1 for the integration times we will propose.

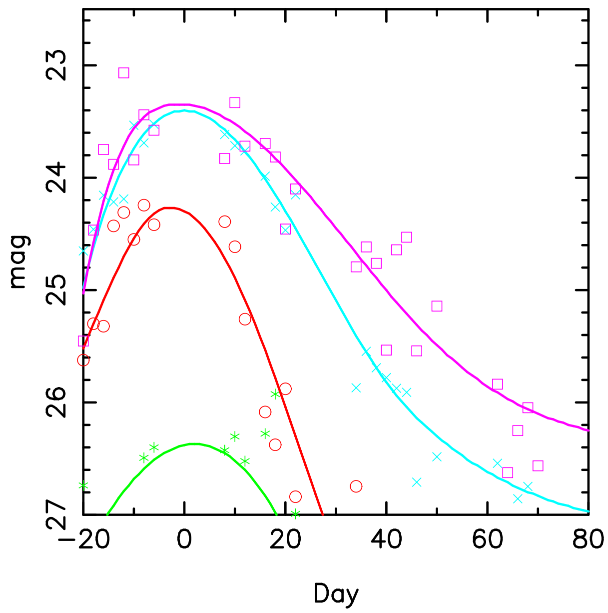

Fig 1: Light curves in SDSS z', i', r', and g', bands (top to bottom). A 14 day dark run is assumed. Observations are conducted every second night, conditions permitting. The Mauna Kea sky is simulated using CFH12K experience. This particular light supernova at redshift 0.854 assumes $q_0 = 0$ and is one of the 40% that have no dust extinction.

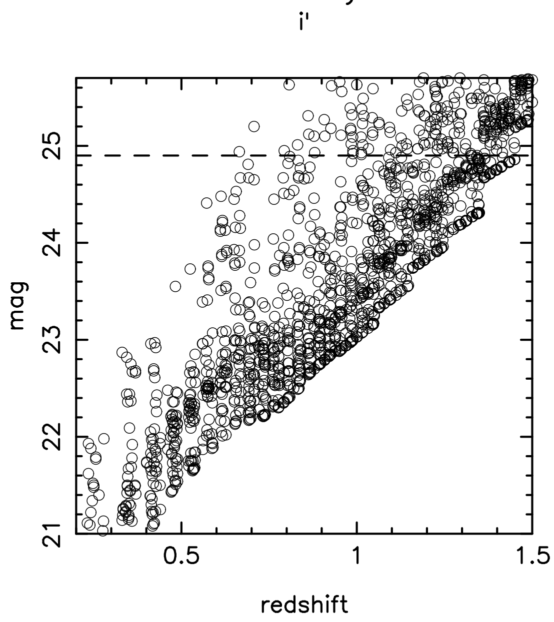

Fig 2: Peak i' magnitudes versus redshift. We expect to reliably derive distances to about redshift one and discover supernovae to about redshift 1.5.

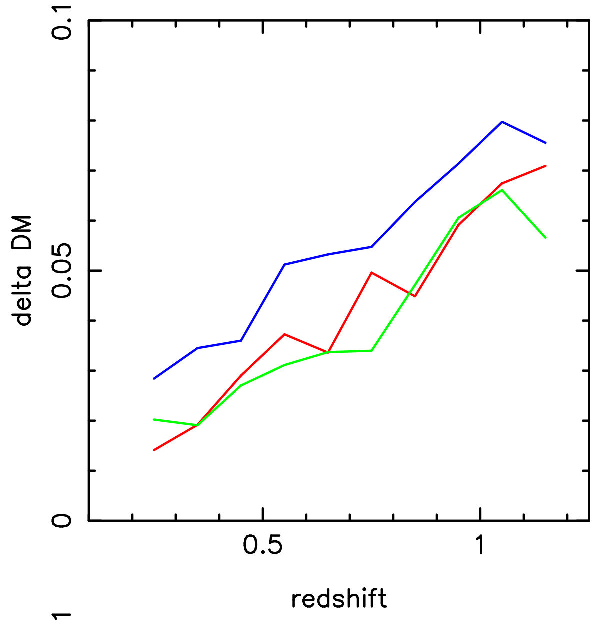

Fig 3: Random error in estimated distance modulus per dust-free supernova as a function of redshift, in the r', i' and z' filters, for 1800 sec exposures. Distances are most efficiently estimated with the i' filter data alone, with other colors measured at peak to measure extinction and control other systematics.

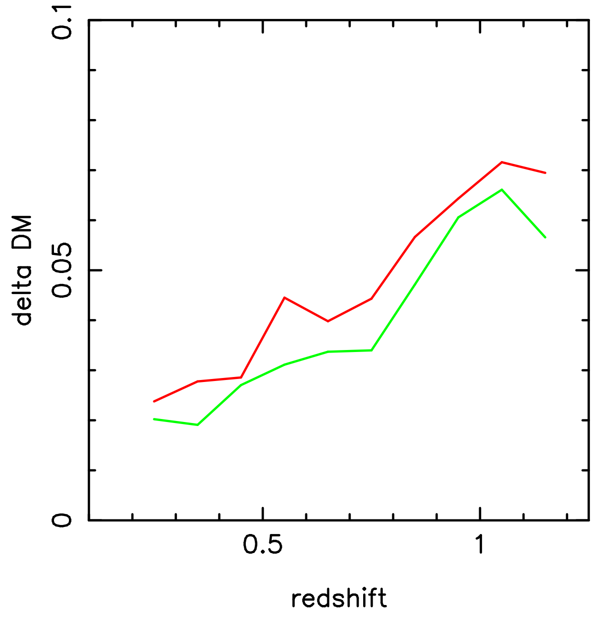

Fig 4: The difference between 14 (green) and 18 (red) day dark runs.

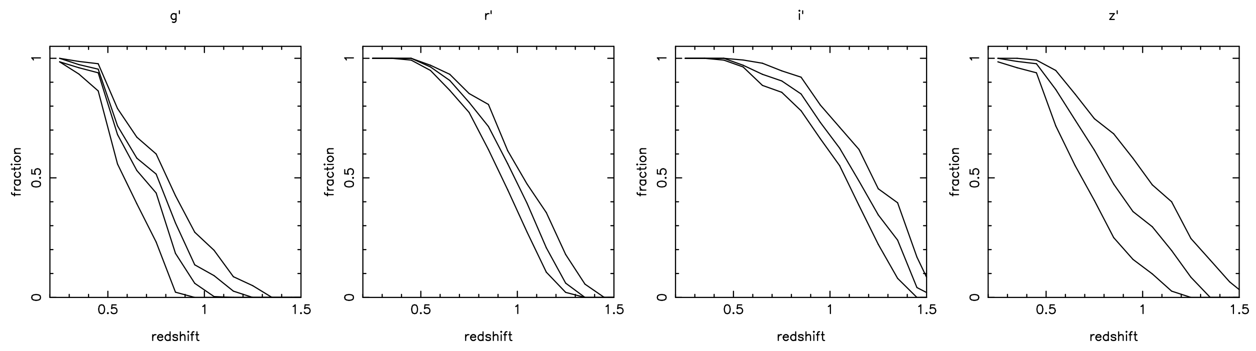

Fig 5: Completeness of Ia luminosity function in (5 min for g') 15, 30 and 60 minute exposures

as a function of redshift.

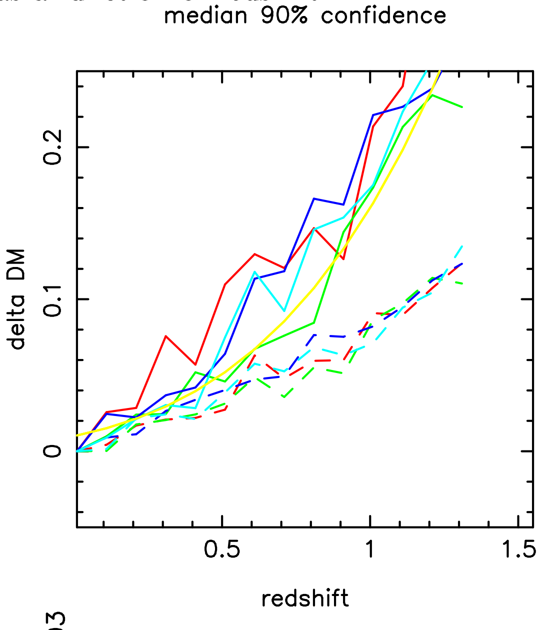

Fig 6: The error per supernova as a function of redshift for our proposed observational strategy as a function of image quality limit. Only those light curves with $\chi^2/dof < 1.18$ are used. The dashed lines are the median error distribution. Blue is for $< 1.2''$, green $< 0.79''$ (median) and cyan is our proposed $< 1''$ (85% of the clear time) image quality. The yellow line is an approximate fit to the estimated errors.

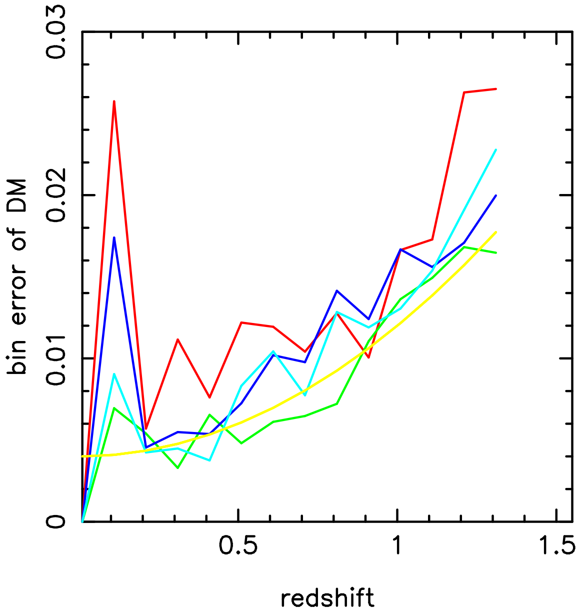

Fig 7: The mean error per 0.1 in redshift interval as a function of redshift for our proposed **five year** observational strategy as a function of image quality limit. Out to redshift 1.5 this produces 2700 Ia supernovae, however only about half of those at higher redshift give reliable fits. Only those light curves with $\chi^2/dof < 1.18$ are used.

3 Cosmology

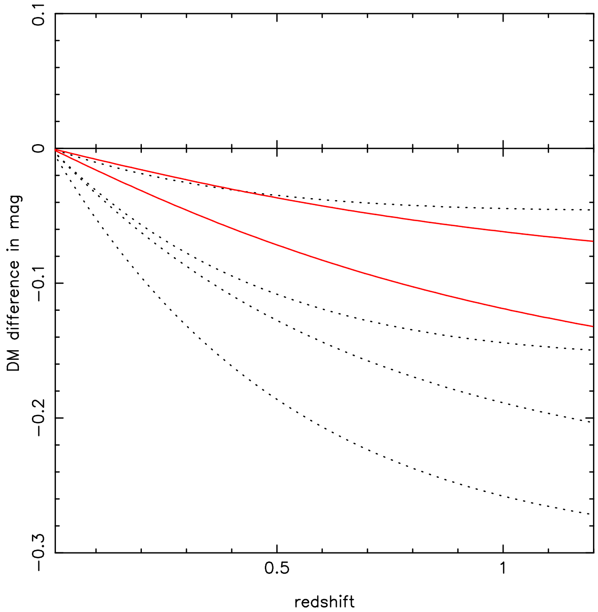

Fig 8: The measurement problem. The reference cosmology has $\Omega_M = 0.3, \Omega_\Lambda = 0.7$ with $w = -1$. The dashed lines are for increments of 0.1 in w. The two red lines are for $\Omega_M = 0.35, 0.4$ showing the partial degeneracy, although this is easily controlled through the weak lensing Ω_M measurement.

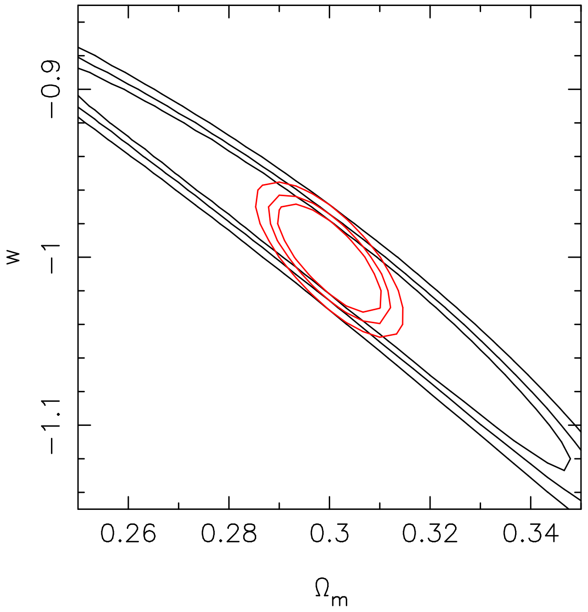

Fig 9: The 68%, 90% and 99% confidence contours in the $\Omega_M - w$ plane for the supernova survey on its own and when combined with the expected 3% Ω_M precision of the weak lensing survey.

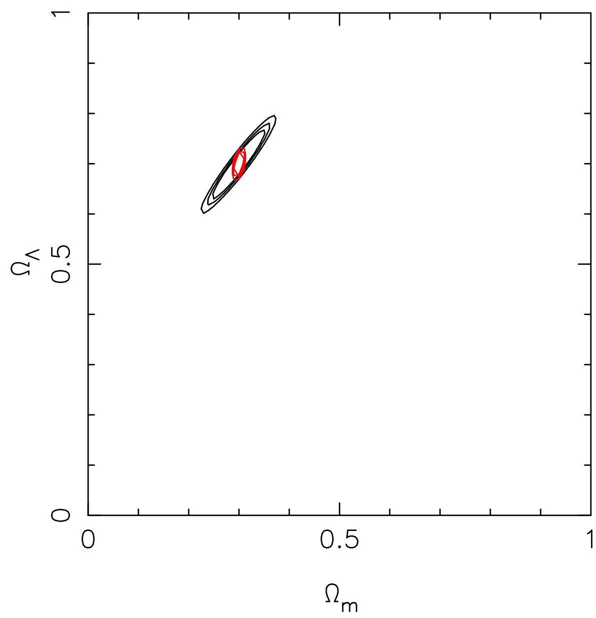

Fig 10: The 68%, 90% and 99% confidence contours in the $\Omega_M - \Omega_\Lambda$ plane for the supernova survey on its own and when combined with the expected 3% Ω_M precision of the weak lensing survey.

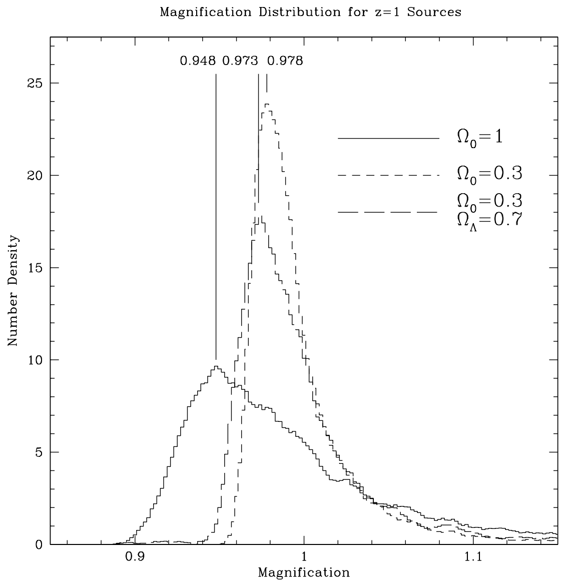

Fig 11: The demagnification distribution due to lensing by large scale structure. This is easily corrected with a low precision (20%) Ω_M measurement.

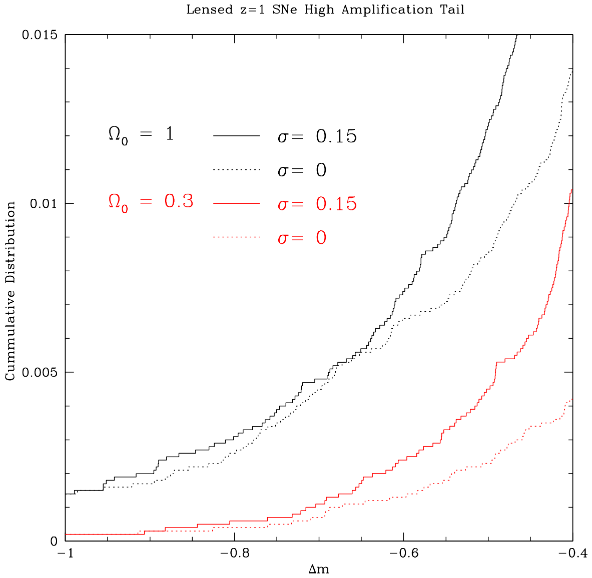

Fig 12: The slightly nonlinear magnification distribution. This is potentially a test of CDM versus "warmed up" CDM dark matter cosmologies.

4 Followup, Survey Variations, Real-Time Analysis

4.1 Followup Spectroscopy

Based on the statistics available there will be 8, 18 and 27 new Ia per month out to redshift 0.8, 1.2 and 1.5. These numbers are controversial at this time. Of the approximately 10 per month per field below approximately redshift 0.9, nearly 8 should be discovered sufficiently near peak to allow 8m spectroscopy. The French experience is that these will require approximately 1 hour (or less) on an 8m (although this estimate is a steep function of brightness and redshift). The cost to obtain spectra of 16 per month is therefore only 16 spectroscopy hours per month. Assuming that the synoptic program is on for 5 of the 6 months of the semester this requires a total of 80 hours, or, approximately 8-10 nights. This load is within the allocations available with the various 8m class telescopes available to the CFHLS partners. It is a fairly large program over the years, however with the available MOS spectrographs the other slits will produce a very large sample of other objects in the fields.

4.2 Followup at other Wavelengths

The partners have available to them various infrared and other telescopes. We expect to apply to obtain infrared photometry and deeper photometry of high redshift candidates using CFHT and other telescopes, in particular large telescopes, available to us. We note that we expect to discover Ia to about redshift 1.5, although they will have little useful light curve information.

4.3 Survey Variations

Could the survey be cut to two or three fields? This is of course possible but it would clearly increase the errors through a reduced sample. It would also leave behind a survey in which the fields were never well placed for continuous easy access for ground based telescopes. Hence it would generally make spectroscopic and other followup more difficult.

An alternate suggestion for the the survey time has been made by Astier and Pain. They suggest 300, 600, 1800 and 1800 seconds for g', r', i' and z' images. To a first approximation the drop in precision of the result is simply proportional to the relative amount of time, 4500 sec as opposed to

8100 sec per epoch, a ratio of 5/9. Hence the errors are approximately 50% larger as shown in the figure below. Consequently what is a 90% confidence result becomes a 68% confidence result, etc. However, the greater concern relates to systematics.

- All of r', i' and z' are expected to have substantial fringing. All of these will have 2-5 images in the standard plan allowing good removal.
- The 50% g' drops to about redshift 0.5 in the cheap plan and redshift 0.7 in z'. This means that many objects will not be visible out of the i' filter, even at peak light. We feel that having accurate colours near peak is crucial to dust measurement and control over anomalous supernovae.

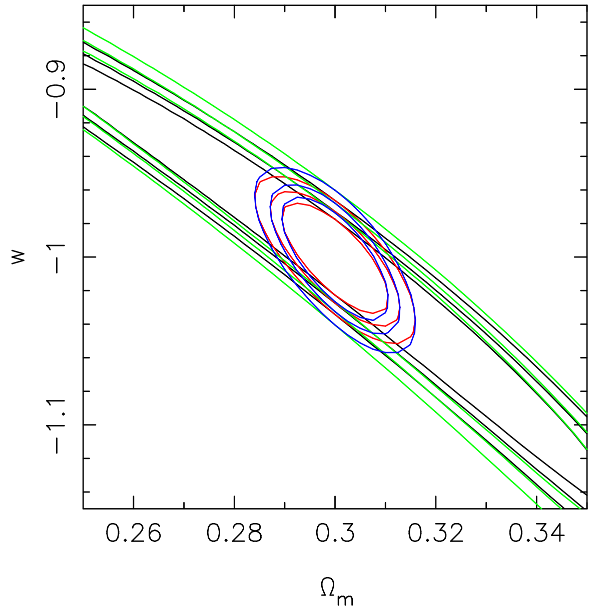

Fig 13: The 68%, 90% and 99% confidence contours in the $\Omega_M - w$ plane for the 8100 sec per epoch survey (black and red contours) and the 4500 sec per epoch survey (green and blue). The 4500s strategy reduces 90% confidence w results to about 68%. Our greater concern is weakened control over systematics with shorter total integration times.

4.4 Real-Time Analysis

We will plan to supply sufficient computing and manpower to undertake real time analysis of the ultra-deep synoptic data. If the bandwidth to Waimea is insufficient we are prepared to place this at the summit although out of the control room and away from the queue team. This team would have the primary responsibility of detecting supernovae on a night by night basis and reporting them to the collaboration. As time was available the team would also undertake data quality assessment for whoever is interested (this does not replace CFHT data quality assessment, but seeks to augment it for various special programs).

The hope is that as methods and techniques mature the real-time analysis will be done entirely remotely. At this stage that cannot be assured, however, we can realistically expect that no more than a single person would be needed after the procedures become fixed.