Date: September 19, 2002	Category: Large Scale Structure, Cosmology	Proposal: F932

CFHT
OBSERVING TIME REQUEST
Semester: 2002A Agency: France

1. Title of the Program *(may be made publicly available for accepted proposals)*:

Cosmology with high redshift Type Ia supernovae.

2. Principal Investigator: **Reynald Pain**

Postal address: LPNHE, Univ. Paris VI and VII, 4, Place Jussieu, T33 RdC 75252 Paris Cedex 05

Fax: (33) 1 44 27 46 38 Phone: (33) 1 44 27 72 53 E-mail: rpain@lpnax1.in2p3.fr

3. Co-Investigators:

Pierre Astier et al	Institute: LPNHE, Univ. Paris VI and VII	E-mail: pierre.astier@in2p3.fr
Pierre Antilogus et al	Institute: IPNL, Lyon, France	E-mail: pierre.antilogus@cern.ch
Dominique Fouchez	Institute: CPPM, Marseille, France	E-mail: fouchez@cppm.in2p3.fr
Saul Perlmutter et al	Institute: LBNL, Berkeley.	E-mail: saul@lbl.gov
Christophe Balland	Institute: IAs, Orsay, France	E-mail: balland@ias.fr
Emmanuel Pecontal	Institute: CRAL, Lyon, France	E-mail: pecontal@univ-lyon1.fr

4. Summary of the Program *(may be made publicly available for accepted proposals)*:

We propose to use the CFH12k camera to discover and *follow-up* $\sim$ 15 Type Ia supernovae at redshifts $z \in [0.4, 1.2]$ for the purpose of improving our measurement of the cosmological parameters $\Omega_{\rm M}$ and Ω_Λ. Unlike previous search campaigns based on observation of the same field at two epochs, we propose to observe the fields every third night, during four consecutive dark runs making it possible to detect and simultaneously measure the light curves of the supernovae. This observing scheme was developed for the supernova program proposed for the CFH Legacy Survey and will be tested for the first time in this campaign. The large redshift range accessible to this proposed scheme makes it possible to measure light curves useful for cosmology up to redshifts $z \sim 0.9$ and to further detect Type Ia supernovae up to $z \sim 1.2$. The CFH12k camera operated in queue mode is the best available instrument to carry out this observation plan. The proposed observing technique makes more efficient use of telescope time than the traditional two-epoch search since it measures and discovers supernovae in the same images. These observations will be coordinated with spectroscopic follow-up (at Keck and VLT), and photometric follow-up (at HST for the faintest objects, and at VLT and Gemini for NIR imaging), in the framework of the SCP international collaboration.

5. Summary of the Observing Run Requested:

Instrument	Detector	Moon (d)	Filters	Grisms
CFH12K	N/A	8	R, I	

Time Req.	Service/Queue?	Queue Mode	Image Quality	Opt. LST	Min. LST	Max. LST
50 hours	Queue	Regular	Not Applicable	N/A	08:00	17:00

6a. Is this a joint proposal? NO 6b. If yes, total number of nights or hours requested from all agencies? —

7a. Is this a Thesis Project? YES 7b. If yes, indicate supervisor: P. Astier.

8. Special instrument or telescope requirements:

9. Scheduling constraints:

We will observe fields at 14^h, 5 times per lunation for 4 consecutive dark runs. The HST awarded time ending in June, we need to observe either from February to May or from March to June. Please contact PI when scheduling.

10. Scientific Justification *(science background and objectives of the proposed observations: 1 page maximum)*:

The Hubble diagram of Type Ia supernovae provides the most direct current measurement of the expansion history of the universe, and has provided the most direct evidence for an accelerating expansion. This evidence has been strengthened by cross cuttings cosmological measurement, in particular recent balloon-based CMB experiments (see for example Netterfield et al. 2001, and Fig. 1a). There are now two important directions to pursue in this proposal:

(A) Extending and filling a SN Ia Hubble diagram up to $z \sim 1.2$. We currently have the opportunity to obtain a Hubble diagram of longlasting value as a record of the expansion history of the universe over the last 10 billion years. This Hubble diagram redshift range that we propose to populate is aimed at addressing several of the more important scientific questions of our day. First, it allows a determination of the curvature of the universe (testing the CMB result) and decoupled measurements of Ω_M and Ω_Λ (see Fig 1). After our proposed observations in semester 2002A, $\Omega_\Lambda = 0$ could be ruled out at well over 3σ. For a flat universe, Ω_M and Ω_Λ could be constrained to $\sim 6\%$. The resulting estimate of Ω_M, for *any* Ω_Λ, is still accurate to ± 0.15 according to simulation. Second, the Hubble diagram out to $z \sim 1$ provides one of the only known ways to constrain the physics of "dark energy" that apparently is accelerating the universe's expansion. There are already physics models that can be ruled out by this improved measurement of a constant equation-of-state ratio, $w \equiv p/\rho$.

The proposed observations will also populate the Hubble diagram in redshift regions already covered, but in a novel way, since lightcurves will be sampled *prior to discovery* in a "rolling search" approach. This continuous observation improves the quality of the distance estimate by providing photometric points on both the rise and the decline. This significantly improves the accuracy of the measurements of both peak brightness (obtained via interpolation rather than extrapolation) and of the time scale of the event, as well as the completeness of the collected sample . This gain with respect to traditional campaigns enables CFHT to play a central role in this science, despite its modest aperture among the involved facilities.

(B) Refining and testing SNe Ia as a cosmological tool : We have shown (Perlmutter, et al., 1997, 1999) that possible systematics in the measurement of Ω_M, Ω_Λ due to K-corrections, gravitational lensing amplification, and Malmquist bias, are small compared to the statistical error. Remaining sources of systematic uncertainty that are unlikely, but possible, are SN Ia evolution and abnormal dust extinction. This proposal addresses these issues: (1) The form of the Hubble diagram at high-z expected for a Λ-dominated universe would be hard to mimic by systematic effects such as intergalactic gray dust or evolution in SN Ia peak magnitudes. Our highest redshift ($z \sim 1.2$) SNe will test this. (2) Comparing spectroscopic measurements of SNe Ia at $z \sim 0.85$ and at $z > 1$ will provide a direct test for evolutionary systematics. (3) the high signal-to-noise measurements from the rolling search technique make it possible to compare the light curve shapes in 2 colors; and (4) use an homogeneous sample of objects at $z \simeq 0.6$ to test for evolution of the peak-brightness vs time-scale correlation. Finally, (5) we can use the set of well-measured high-z SNe to check for the increased dispersion in absolute magnitude expected from evolution or abnormal dust extinction.

Progress to date The recent campaign of 2001A yielded 13 confirmed SN Ia events, among which 7 were discovered in the deep exposures taken at CFHT. Five candidates were photometrically follow-up at HST, with 2 objects beyond $z = 1$. Figure 2 shows preliminary analysis of the highest redshift SN Ia that was discovered at CFHT, spectroscopically confirmed at Keck, and followed with HST.

A pilot run for the CFHLS: The new observing strategy envisioned for the supernova part of the CFHLS requires the development of procedures and algorithms to be tested on real data, in order to ensure as high as possible an efficiency from the very start of this huge program. This "rolling search" proposal aims at providing such a data set. We would therefore provide access to this proposed CFHT data for the purposes of preparing for the CFHLS.

Conclusion: SN Ia are the best demonstrated technique to study the cosmological parameters that determine the expansion. CFHT has the potential to play the pivotal role in this exciting science using the novel "rolling search-and-follow-up" technique proposed here, by providing higher quality measurements for ~ 15 Type Ia supernovae at redshifts, $z \in [0.4, 1.2]$.

11. References *(1 page maximum)*:

Netterfield, C.B. et al, 2001, astro-ph/0104460.

Pain., R. et al, 1996, ApJ, 473, 356.

Pain., R. et al, 2000, to be published.

Perlmutter, S. et al., 1997, ApJ, 483, 565.

Perlmutter, S. et al., 1999, ApJ, 517, 565.

12. Figures *(all figures must appear on a single page)*:

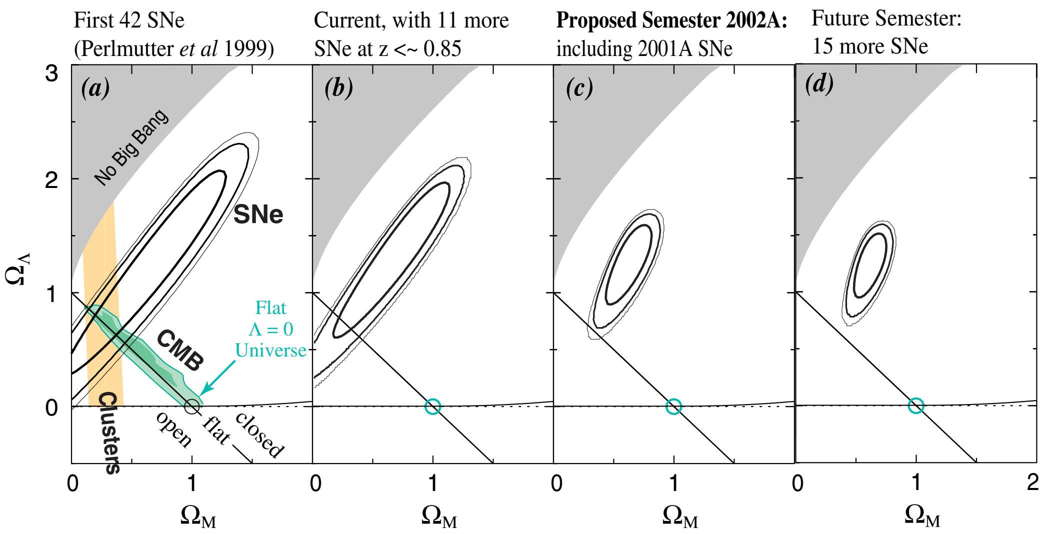

Figure 1: Achievable precisions with the targetted statistics. A non flat universe was choosen on purpose as the central value of the contours.

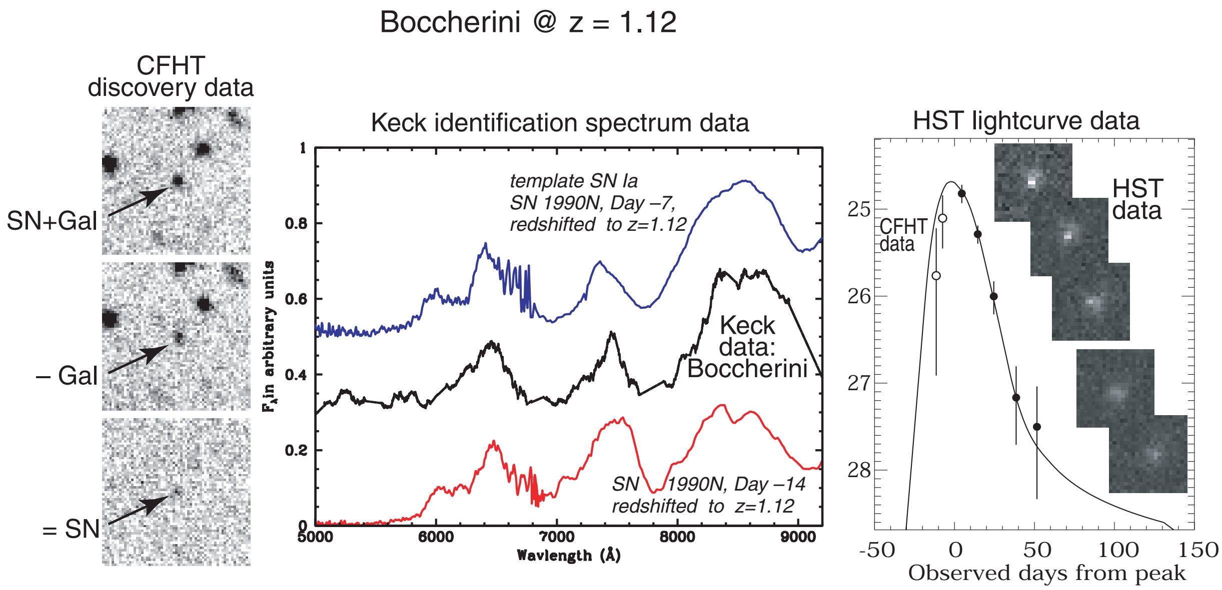

Figure 2: A z=1.12 SN, nicknamed "Boccherini", from our 2001A campaign. CFH12k discovery images and image subtraction. Spectrum from Keck/ESI. Preliminary light curve, with HST images.

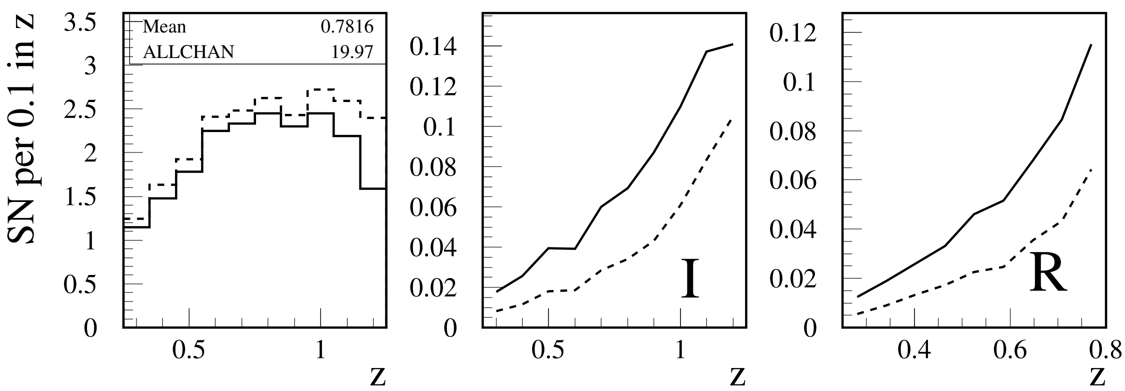

Figure 3: a) Expected z distribution of SN (dashed line: detection only, full line: good light curve sampling). b) and c): r.m.s resolutions of fitted peak brightness as a function of redshift (dashed line: raw peak brightness, full line: corrected for stretch).

13. Technical Justification

(provide technical details of the proposed observations; justify the use of the CFHT, the requested instrument configuration, and the amount of telescope time requested: 1 page maximum):

We propose to image three adjacent CFH12k fields every third night of a dark run, for 4 dark runs in a row, to discover and photometer Type Ia SNe. At each of 20 total epochs, each field will be observed for 30 mn in I and 10 mn in R. Along with the initial detection of SNe, the continuous sampling strategy allows the CFHT data to provide most of the lightcurve measurement, depending on the SN redshift as follows:

- $0.4 < z < 0.7$: the R and I images respectively measure the restframe B and V lightcurves.
- $0.7 < z < 0.9$: the I images measures the restframe B lightcurve.
- $z > 0.9$: the I images detect the SN and measures the date of restframe U maximum.

Where necessary the peak restframe V (to measure color) will be measured at VLT+Isaac, Gemini, or in the F850LP filter of $HST + WFPC2$. Precise photometric measurements for $z > 0.9$ SNe rely on imaging with VLT or HST (with 100 HST orbits awarded for use in 2002A).

Simulator: We have used a Monte-Carlo simulator to aid in the design of the observational program. It is based on a SN generator, an instrument simulator (which reproduces the measured 12k sensitivity) and a weather simulator (which reproduces seeing, extinction and weather variations observed at Mauna Kea). This simulator uses the recent measurement of the SN Ia rates based on 40 objects at redshifts $0.4 < z < 0.8$ (R. Pain *et al*, 2001) and reproduces the observed statistics of our previous CFHT runs.

Detection: We propose to use the following scheme to select candidate SNe: at each epoch a deep reference is subtracted off the I images, and light increases above 3σ are recorded. Spectroscopy will be obtained for those candidates detected at three epochs and having a combined detection greater than 7.5σ. Figure 3 displays the expected redshift distribution (for 1 square degree), where only points on the rise of the light curve contribute to the detection. The small loss of efficiency at low redshifts is due to our requirement that 3 points on the rise are actually observed.

Photometric accuracy: The photometric accuracy of the simulated observations was translated into a peak brightness accuracy via a fit of a template to simulated lightcurves. Figure 3 displays the r.m.s scatter of the fitted peak magnitude from Monte-Carlo lightcurve realizations. The raw peak brightness uncertainty enters the color correction, while the stretch corrected peak brightness is the distance indicator. The accuracy we expect to reach is comparable to, or better than, that for the SNe Ia in Perlmutter et al, 1999.

Areal coverage : 1 square degree yields about 20 objects in the redshift range $0.25 < z < 1.25$ (see Fig 3). We anticipate possible losses due to bad weather at follow-up, and temporary unavailability of HST for 1 month during spring 2002. We thus expect 15 identified and measured SNe Ia, with 2 beyond $z = 1$. Since the HST requires target coordinates within 1° three weeks prior to discovery, our fields must be grouped.

Deep references: From our previous searches we already have very deep reference images in I for two CFH12k fields located in the 14^h VIRMOS field. For the third field, a reference image has to be taken before or at the start of the run. Lightcurves in R also require a reference image. The standard exposure time of 1h that VIRMOS uses in this filter is adequate for this purpose, but our deep I fields are not yet covered in R band. Thus, we also need to obtain reference images in R. As the observations progress, we will progressively make use of more than one month old images as references for the detection.

Summary of the observing time request: For 3 fields observed 20 times 40 mn (30 mn in I and 10 mn in R), the total integration time is 40 hours (240 images of 10 mn), plus 4 hours for readout. We need a 4 hour I reference for the third field, for which 1 hour already exists. We also need 3 hours in R to aquire a 1 hour reference of the third field. Our total request then amounts to 50 hours.

Observing conditions: Our observations have to be performed every third night, at airmass below 1.5. Our median seeing should stay below 0.9, and we can occasionaly accomodate seeings up to 1.2″.

Why use CFH12k? We plan to carry out 40 observations of 3 fields, resulting in a total of 120 images. These 120 images will provide about 300 lightcurve points for Type Ia SNe. Thus, our proposed plan offers a large multiplex advantage enabled by CFH12k, and which capitalizes on the availability of the QSO.

Computing resources: We have already successfully used our computers in Waimea to flatfield and subtract images: we are able to process 24 deep subtractions in less than 6 hours. This scientific program requires as fast as possible access to raw data.

14. Targets:

Object/Field	α	δ	Epoch	Mag/Flux	Comment

15. General Target Information:

Our targets will lie in the Virmos 14h field (14h 00, +5 00)

16. Is this program conducted in relation with other observations (optical, radio, space)?

YES: To use supernovae for cosmology, we need to identify them and to measure their redshifts. This will carried out at Keck and VLT. Getting a color measurement at peak brightness involves IR photmetry at VLT or GEMINI. Precise light curves of high redshift objects will be obtained using HST time (already awarded).

17. How many additional nights or hours at CFHT would be required to complete this project? 0 hours

18a. Is an extension of the one-year proprietary period required? NO 18b. Proposed proprietary period? 12 months

18c. If yes, justify the request for an extension:

19. Recent Allocations on CFHT and Other Telescopes:

- cfht 99b: 2x1.5 nights on 12k. 2 pointings searched (1 bad half night on the second epoch), 14 candidates found, spectra at Keck for 8 of them, and followed-up one at VLT. HST went out of service after the search. VLT photometry data reduced.
- cfht 2000a: 2x2.5 hours observed (with high sky background). 1 candidate at z=0.54 found very early (about 14 days before maximum) followed photometrically and spectroscopically for systematic studies. Final references (optical and IR) obtained in 2001A.
- cfht 2001a : 38 hours in queue. Due to bad weather at first epoch, only 17 hours actually used (i.e. two 12k deep pointings). We found 13 candidates, 6 were observed at Keck and identified, among which two are beyond z=1. We need final HST references to produce the light curve. The whole campaign identified 13 objects.

20. Publications Resulting from CFHT Observations *(only the 12 most recent contained in the database are displayed)*:

C.Lidman, A. Goobar and R. Pain 2000, ESO messenger, accepted
P. Astier et al. 2000, Moriond, accepted
S. Fabbro et al., on behalf of the SCP, 1999, IAUC, 7311, accepted

21. Experimental Design *(additional scientific and technical details for large programs: 2 pages maximum)*: